INTEGRATING WATTMETERS

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ARMOUR INSTITUTE OF TECHNOLOGY

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A COMPARATIVE TEST

OF

INTEGRATING WATTMETERS

A THESIS

PRESENTED BY

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OF

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The object of this thesis is to make a test on the Fort Wayne and Sangamo Integrating Wattmeters to determine the effect upon the accuracy of the meters under varying conditions as to power factor, frequency, and voltage at various loads. Also to determine the variation from quadrature of the series and pressure fluxes.

APPARATUS.

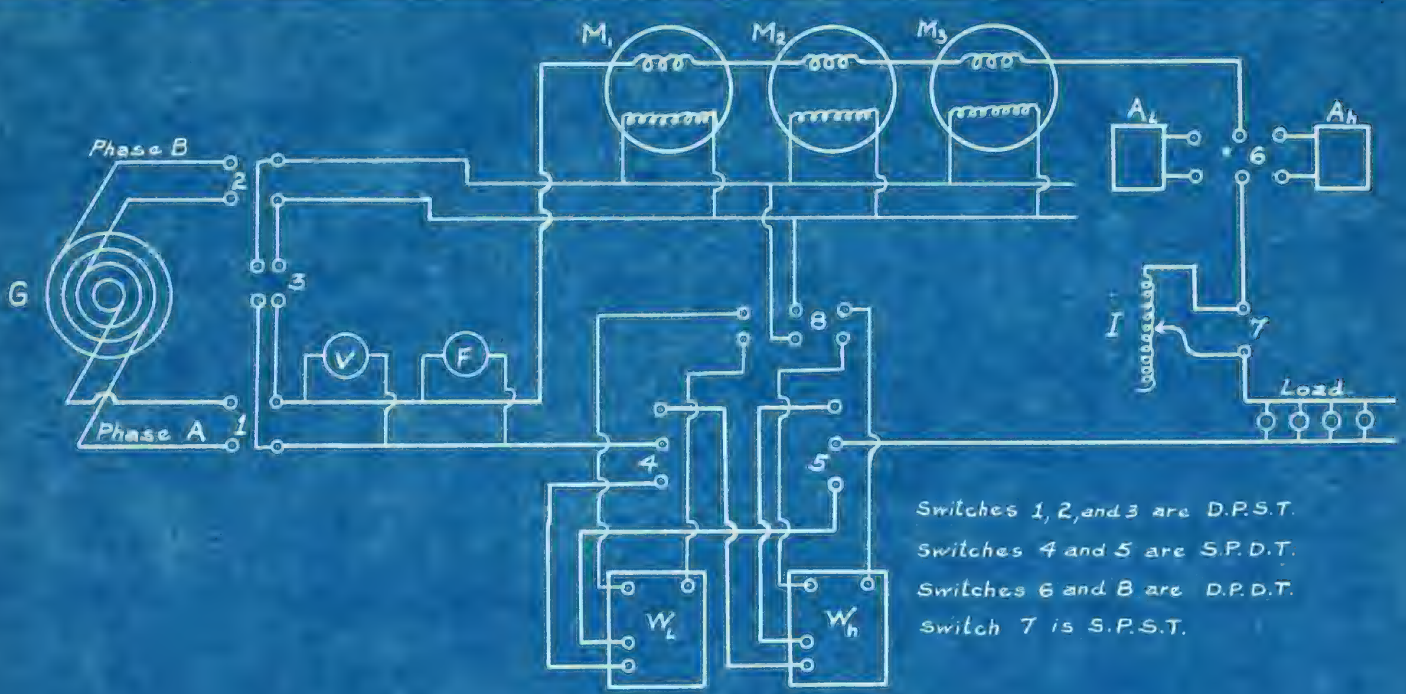
2 General Electric Ammeters,	(0-10) & (0-15)
1 Weston Voltmeter,	A.C. & D.C. (0-125)
2 Weston Wattmeters,	(0-10) & (0-25)
1 Frequency Meter,	(30-90 cycles)
Variable Inductance.	
Variable Condenser.	
Lamp Bank.	
Stop Watch.	
Switches.	

21672

REFERENCES.

In preparing this thesis, the following references were used:

Electrical World, June 16, 1906.
American Meter Practice, Reed.
Electric Meters, Gerhardi.
Alternating Currents, Lamb.
Alternating Currents, Russel.
Electricity Meters, Solomon.
U.S. Patent #531867.
Bulletins from the different manufacturers.



Switches 1, 2, and 3 are D.P.S.T.
Switches 4 and 5 are S.P.D.T.
Switches 6 and 8 are D.P.D.T.
Switch 7 is S.P.S.T.

Scheme of Connections.

DESCRIPTION OF THE SCHEME OF CONNECTIONS.

The scheme of connections for making the tests is shown in the accompanying blue print. (G) is a two phase alternator supplying the two phases (A) and (B). (M_1), (M_2), and (M_3) are the integrating wattmeters under test. (F) and (V) are the frequency and voltmeters. (A_1) and (A_2) are the low and high reading ammeters. (I) is a variable inductance. (W_1) and (W_2) are the low and high reading indicating wattmeters. The leads from switch 2 connect directly to the pressure circuits of the meters, and the leads from switch 1 connect the load or series elements of the meters. Switch 1 will be closed during all of the tests. The switches 4 and 5 are used to connect the series coil of either the high or low reading wattmeters in the load circuit. The D.P.D.T. switch 6 is used to connect either the high or low reading ammeter in circuit. Switch 7 is used to cut the inductance coil (I) in or out of circuit. Switch 8 gives pressure to the indicating wattmeters from either phase (A) or phase (B). Switch 3 is used to give the integrating wattmeters pressure from either phase (A) or phase (B). When switch 3 is closed, switch 2 must be open or there will be a short circuit. For the quadrature test, switches 1 and 2 are closed and 3 is open. Then the meters are taking their pressure

[illegible]

The [illegible]

is shown in the illustration [illegible]

shows differences [illegible]

(A1), (A2), and (A3) are the normal [illegible]

[illegible] (A4) and (A5) are [illegible]

(A6) and (A7) [illegible]

[illegible] importance. [illegible]

[illegible] indicating wettish [illegible]

[illegible] cannot directly to the [illegible]

The seeds, and the leads from which I [illegible]

[illegible] series [illegible]

[illegible] during all of the tests. [illegible]

[illegible]

[illegible]

[illegible] is used [illegible]

or low reading [illegible]

to cut the [illegible]

method [illegible]

then, either [illegible]

[illegible]

group (A) or group (B). [illegible]

[illegible] them [illegible]

[illegible]

is [illegible]

from phase (B). By opening 2 and closing 3, the meters take their pressure from phase (A). The voltmeter and frequency meter are connected directly across the pressure circuit.

METHOD EMPLOYED IN MAKING TESTS FOR ACCURACY AND QUADRATURE.

The meters were first connected up so as to take their load and pressure from the same phase (A). They were then adjusted accurately on full non-inductive load, using normal voltage and normal frequency, in the following manner. The full non-inductive load, which was obtained by means of a lamp bank, was sent through the meter under test, and the voltage and frequency were adjusted accurately and maintained constant. The time it took to make a certain number of revolutions of the disc was observed by means of a stop watch and at the same time the reading of the indicating wattmeter was taken. The constant of the meter multiplied by the number of revolutions and divided by the time it took to make those revolutions gave the watts recorded by the integrating wattmeter. Now if we call the reading of the indicating wattmeter the standard watts, and the watts recorded by the integrating wattmeter the meter watts, then the per cent accuracy of the meter is

$$\text{per cent accuracy} \quad \frac{\text{Meter Watts X 100}}{\text{Standard Watts}}$$

All of the meters were adjusted to show 100% accuracy under the above conditions by moving the damping magnets as the case required. The compensating coils were adjusted to overcome the friction of the meters. After adjusting the meters on full load, the load was varied from about 10% to 130% of normal full load current, using normal voltage and frequency, and the accuracy was determined in each case. The meters were not adjusted, however, on these other loads.

The next test was to determine the variation from quadrature of the series and pressure fields on full non-inductive load. This was done in the following way. The load was taken from phase (A) and the pressure from phase (B). The e.m.f.s in the two phases were of course 90° apart. The Weston indicating wattmeter was connected with its series coil in phase (A) and with its pressure across phase (B). Now with these connections, if the series and pressure fluxes were in exact quadrature, the reading of the indicating wattmeter would be zero when the disc was at a standstill. It was found, however, that they were not in exact quadrature, and therefore when the disc stopped there was a reading on the Weston wattmeter. The disc was brought to a standstill by means of a condenser in parallel with the lamp bank. Dividing the true watts by the volt-amperes gave the cosine of ϕ, or the angle between

The series and shunt fields.

The next test was a test for accuracy under the following conditions. The voltage was kept at normal value and the frequency was also maintained constant at normal value. Then the effect of a variable load at different power factors was noted.

The next test was to determine the variation from quadrature of the series and pressure fluxes at different frequencies. Also, at each frequency, the load was varied and the accuracy of the meter determined, the voltage remaining constant at normal value and the load being at unity power factor throughout the test.

The next test was to determine the accuracy of the meter when the voltage was varied from 25% below to 25% above normal. During this test the frequency remained constant at normal value and the load was at unity power factor.

The general principles involved in induction meters are well stated in a patent issued to Oliver B. Shallenberger in 1894. I will here give the first three claims in his patent No. 531867.

Claim 1. The method of measuring the energy transmitted by single phase alternating electric currents, which consists in establishing two alternating magnetic fields, one proportional to, and in phase with the current transmitted to the work circuit, the other derived from, and proportional to the impressed electromotive force of the work circuit and lagging approximately 90° behind that electromotive force, producing by such two magnetic fields a resultant shifting magnetic field, producing by such resultant field mechanical motion against a force which is proportional to the speed, and registering such motion.

Claim 2. The method of measuring the energy transmitted by single phase alternating electric currents, which consists in developing two alternating magnetic fields, one proportional to and having a definite phase relation to the current transmitted to the work circuit, the other derived from, and proportional to the impressed electromotive force of the work circuit and under varying conditions of lag in the work circuit differing from the first field by approximately the complement of the angle of such lag, producing by such two magnetic

fields a resultant field, producing by such resultant field mechanical motion against a force which is approximately proportional to the speed, and registering such motion.

Claim 3. In an electric meter for alternating currents, operated by induction effects of currents in a shunt connected and a series connected coil, the method of compensating for changes in periodicity which consists in inductively varying the shunt current in an inverse ratio to the periodicity.

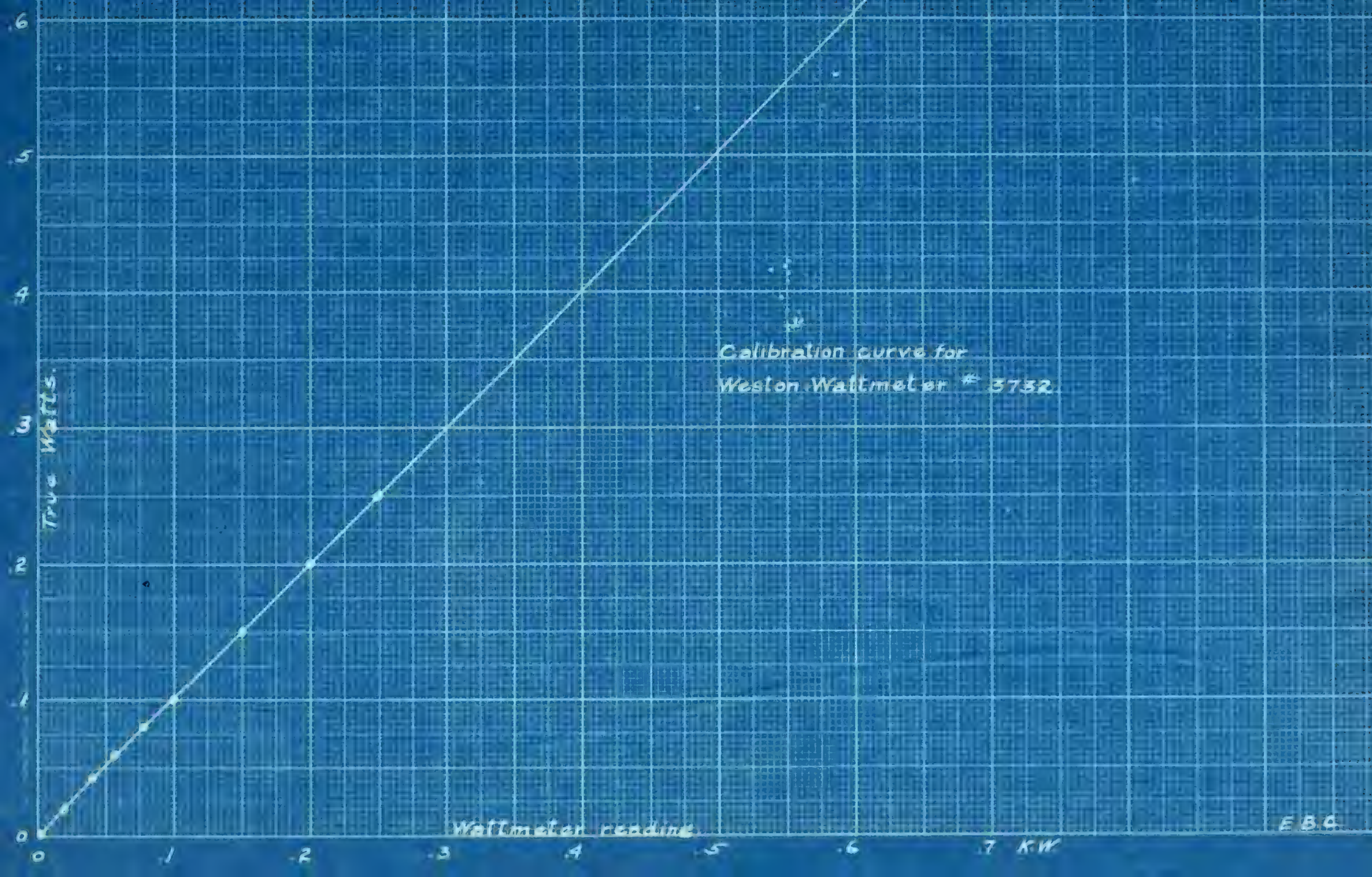
CALIBRATION OF INSTRUMENTS

CALIBRATION OF INSTRUMENTS.

The two General Electric ammeters used in this test were new and were assumed to be correct. Therefore I did not have to calibrate a dynamometer. The voltmeter and the two wattmeters were checked up in the testing room at Armour Institute by means of a potentiometer. Calibration curves were then plotted and the true watts or volts were obtained from these curves.

Calibration of Weston Wattmeter #3732.

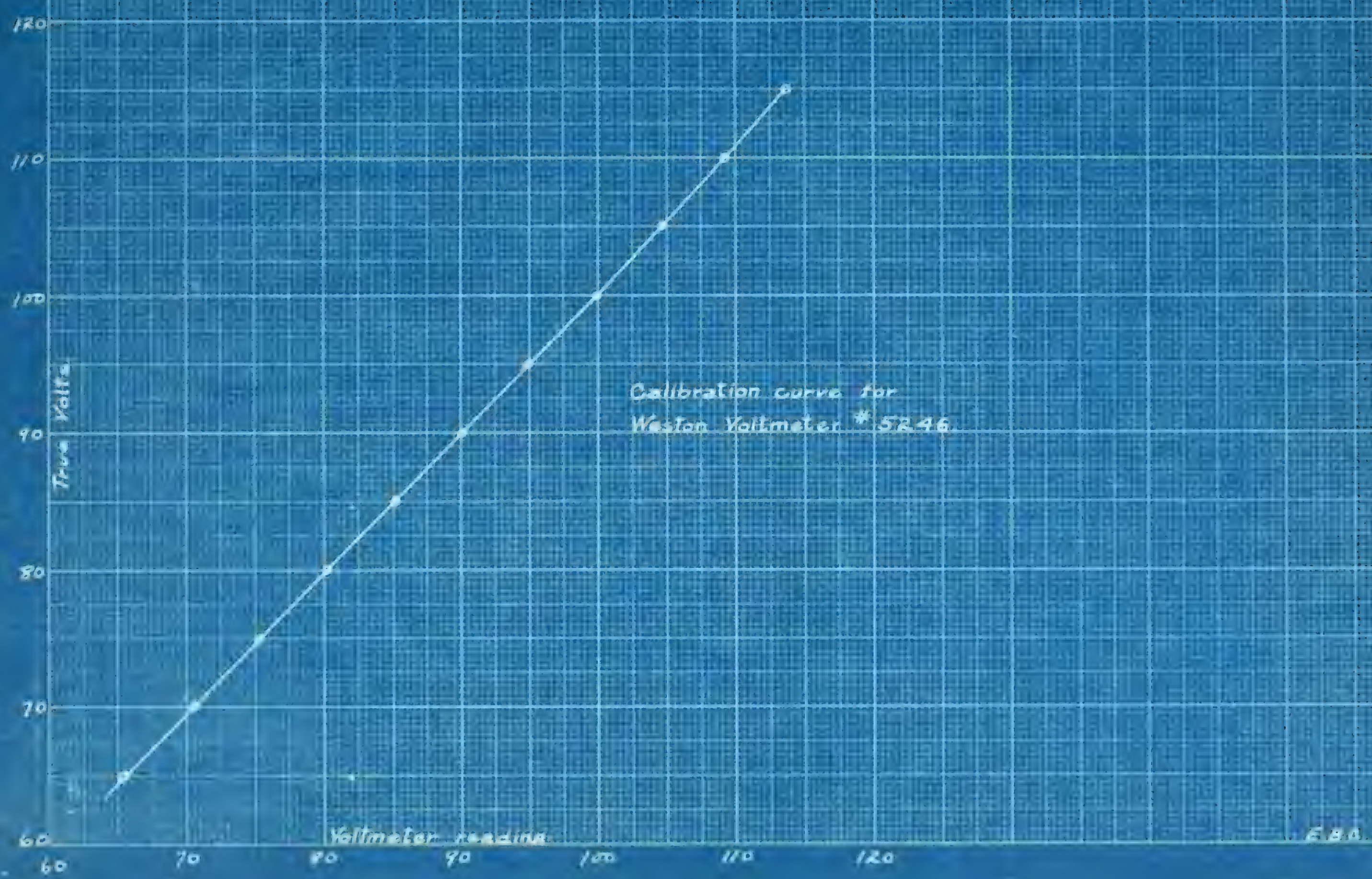
Amperes	Volts	EI	Wattmeter rdg.
.2	100	20	18
.4	100	40	38.5
.6	160	60	54.25
.8	100	80	78.75
1.0	100	100	100.0
1.2	100	120	120.5
1.5	100	150	150.0
2.0	100	200	199.5
2.5	100	250	248.75
7.0	100	700	693.5



Calibration curve for
Weston Wattmeter # 3732

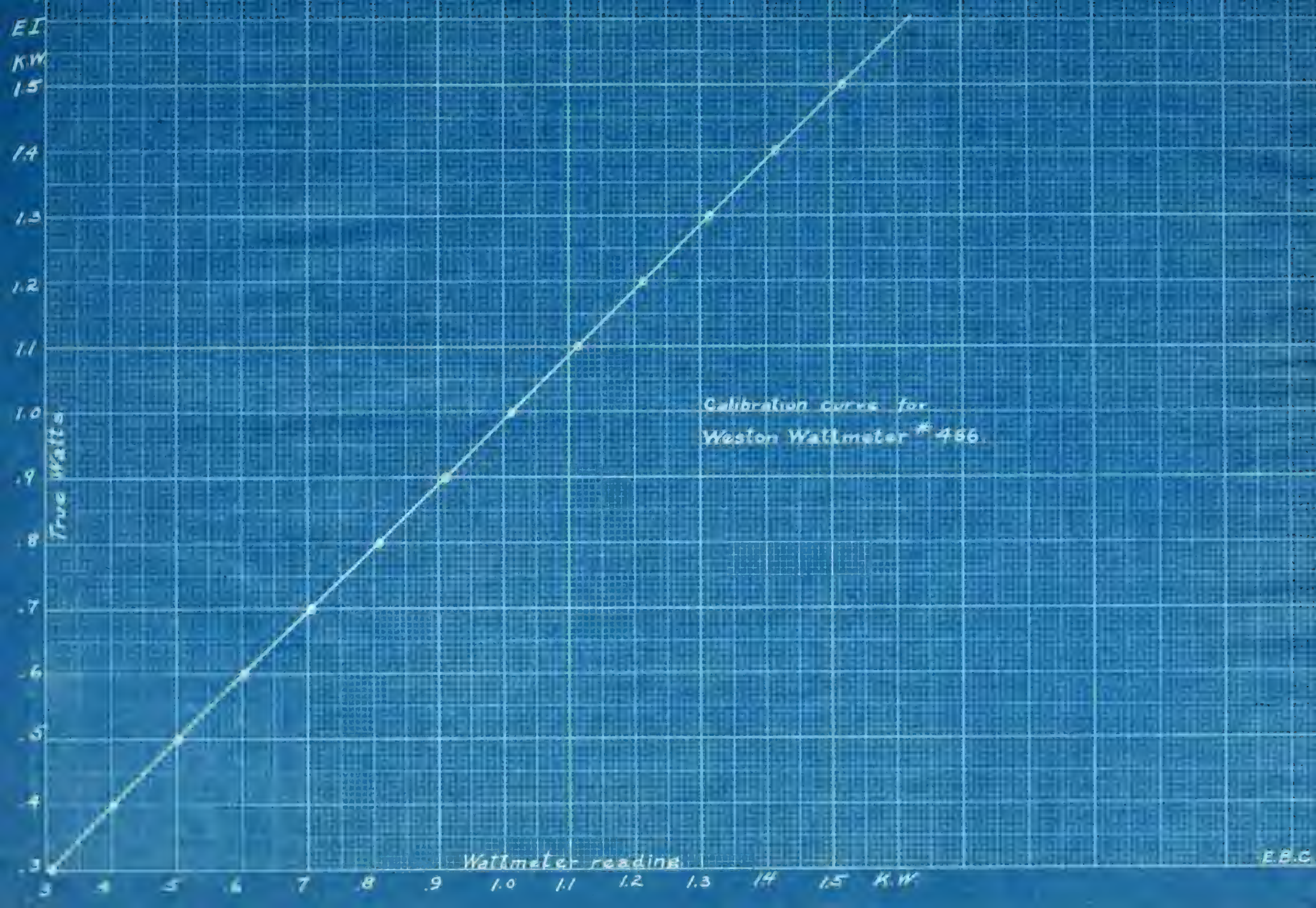
Calibration of Weston Voltmeter #5246.

Standard Voltmeter.	Weston Voltmeter.
75	75.3
80	80.2
85	85.15
90	90.05
95	95.0
100	99.85
105	104.65
110	109.1
115	113.65


Calibration curve for
Weston Voltmeter # 5246
True Volts
Voltmeter reading
120
110
100
90
80
70
60
60
70
80
90
100
110
120
E.B.A.

Calibration of Weston Wattmeter #466.

Amperes.	Volts.	EI.	Wattmeter r'd'g.
1.01	100	101	100.5
2	100	200	200.5
3	1000	300	303
4	100	400	400
5	100	500	502
6	100	600	605.5
7	100	700	707
8	100	800	809.5
9	100	900	910
10	100	1000	1009.5
11	100	1100	1110.5
12	100	1200	1206.5
13	100	1300	1312.5
14	100	1400	1414.5
15	100	1500	1515.5



Calibration curve for
Weston Wattmeter # 466.

THE FORT WAYNE INDUCTION WATTMETER.

Type K. No. 452568

Volts 110 Amperes 10 Cycles 60.

The Fort Wayne Induction Wattmeter of this type has a rotating element, or armature, entirely different from that in any of the other types of wattmeters. The armature in this meter is mounted on a vertical shaft and is cup shaped, instead of being in the form of a disc as in the other types of meters. In some forms of the type K meter one permanent magnet is used and in others two, the magnets being specially shaped so as to embrace the cupped armature. The adjustment in both types is obtained by moving the magnets up or down, depending upon whether the speed is to be decreased or increased. The light load adjustment is obtained by shifting a small iron core in the path of the shunt magnet which distorts the shunt field slightly. In Fig.1 of the accompanying blue print, I have shown a diagram of the Fort Wayne meter, only showing however the relative positions of the shunt and series coils and the rotating element. This combination of the series and shunt fields produces a rotating field which induces current in the armature, which acts as a closed secondary, thus causing rotation of the same.

Fig.2 shows the complete internal connections of this meter, when the shunt and series elements are separately connected to two independent circuits for

Fig. 1.

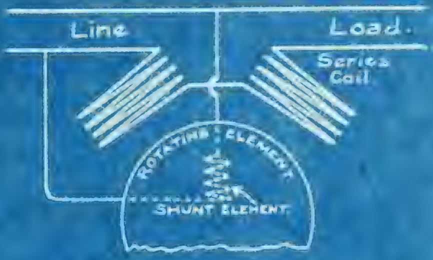


Fig. 2.

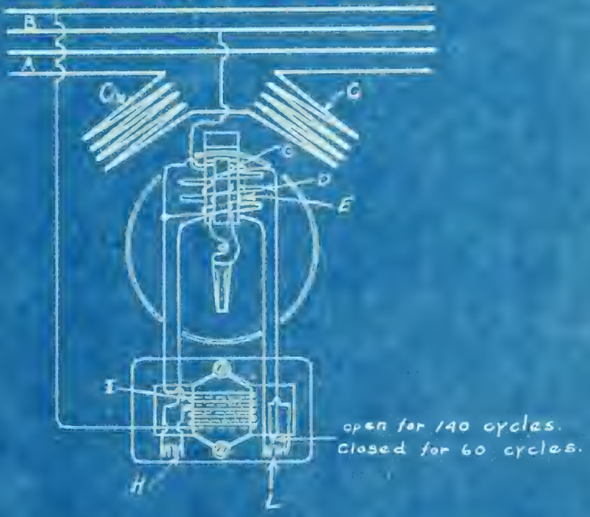


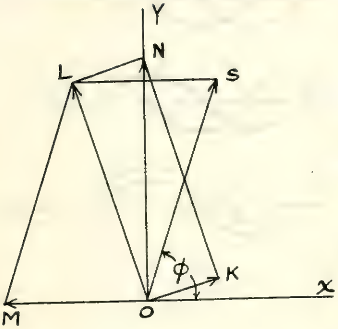
Diagram of a type K

Fort Wayne Induction Watt Hour Meter

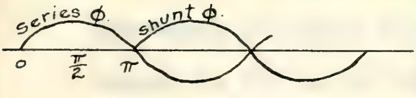
a quadrature determination. (A) and (B) are the two independent circuits. (C&C) are the series coils. The coil (E) is wound on the shunt core with the shunt coil (D) and is used to obtain the 90° phase relation between the series and shunt fields on 60 cycles. This coil creates a field, the magnitude of which is determined by the 60 cycle lagging resistance (L) in series with it. The coil (G) is wound on the light load adjusting arm, and is shunted across a few turns of the impedance coil (I). This coil tends to produce a component field, the magnitude of which is determined by the 140 cycle lagging resistance (H). With this coil it is possible to get the proper phase angle of 90° between the series and shunt fields on 140 cycles. Before these meters leave the factory, the resistances (H) and (L) are adjusted to the proper values so that the meters can be used for either high or low frequencies.

The method employed in obtaining the phase displacement of 90°, or lagging the meter as it is called, is given below. Two separate circuit are used and the series and pressure coils are connected across the two phases as shown in Fig.2 of the blue print. Full non-inductive load is sent through the series coils in phase (A) and the normal electromotive force of the meter at 140 cycles is impressed on phase (B). The e.m.f. of phase (B) however is lagged 90° back of that impress-

ed on phase (A). Then the 140 cycle lagging resistance (H) is adjusted until the meter stops. This indicates a no torque phase relation between the series and shunt fields. The vector diagram given below shows how this quadrature is obtained.

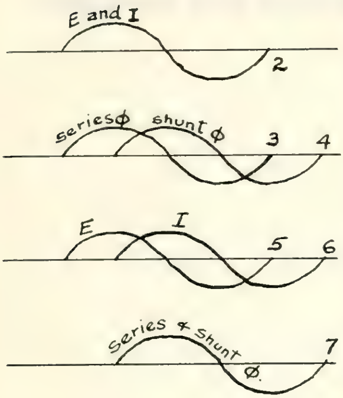


Let OX represent the e.m.f. impressed on phase (B), and let OY represent a position 90° from OX. The shunt field lags behind the e.m.f. by an angle ∅, due to the inductance of the coil (D) and the impedance coil (I). Represent its position by the vector OS. This shunt field OS induces in the armature currents and consequent fields. Represent the fields set up by the armature by the vector OM. Now OS and OM combine to give the resultant field OL. By means of the lagging resistance (H) the coil (G) can be made to produce a field OK which, when combined with OL, will give the resultant field ON, 90° from OX.



Curve 1.

When the rotating element stops, indicating a no torque phase relation between the series and shunt fields, it will be seen that the fluxes produced by the series and shunt coils are displaced by 180° as shown in curve



(1) at the left. 90° of this is due to the initial phase difference between the electromotive forces impressed on the circuits (A) and (B), and 90° is due to the inductance of the pressure coils. Now when the pressure and series coils are connected to the same circuit, in which the impressed e.m.f. and current are in phase as shown in curve (2), we have eliminated the fixed displacement of 90° and there remains only the maximum torque displacement of 90° between the series and pressure fluxes as shown in curves (3) and (4). Now if the power factor of the load be made zero as shown in curves (5) and (6), then curve (3) will coincide with curve (4) and there will be no phase difference between the series and pressure fluxes, and hence no torque, as shown in curve (7). From this discussion it can be seen that as the power factor of the load decreases, the current in the shunt circuit comes more nearly into phase with the impressed e.m.f. and hence the meter will have a torque directly proportional to the cosine of the angle of lag, and hence the true energy will be measured for all power factors.

The Fort Wayne meter has one distinctive feature

namely, the series coils are wound without an iron core and hence have little or no inductive effect.

THE SANGAMO INTEGRATING WATTMETER.

Type E. No. 76671

Volts 110 Amperes 10 Cycles any.

The Sangamo Integrating Wattmeter is not of the induction type and therefore it is not necessary to obtain a quadrature relation between the primary fields in order to have the meter register true energy on low power factors, but the opposite condition holds, namely, to obtain a coincidence of phase between the armature current and the series field. This meter is of the mercury type the general principle of which is given below.

Faraday discovered that when a current was passed radially across a disc which was immersed in mercury, the path of the current being subjected to a strong magnetic field, the reaction between the current and the magnetic field produced rotation of the disc.

The diagram of the Sangamo meter is shown in the accompanying blue print. The armature (D) consists of an aluminum disc mounted on a vertical shaft. This disc is immersed in a cup of mercury. On the upper part of the shaft is another disc (B) which revolves between two permanent magnets. (M) is the series coil which is wound on the laminated iron yoke (Y). A small transformer (P-S) furnishes a large current at low pres-

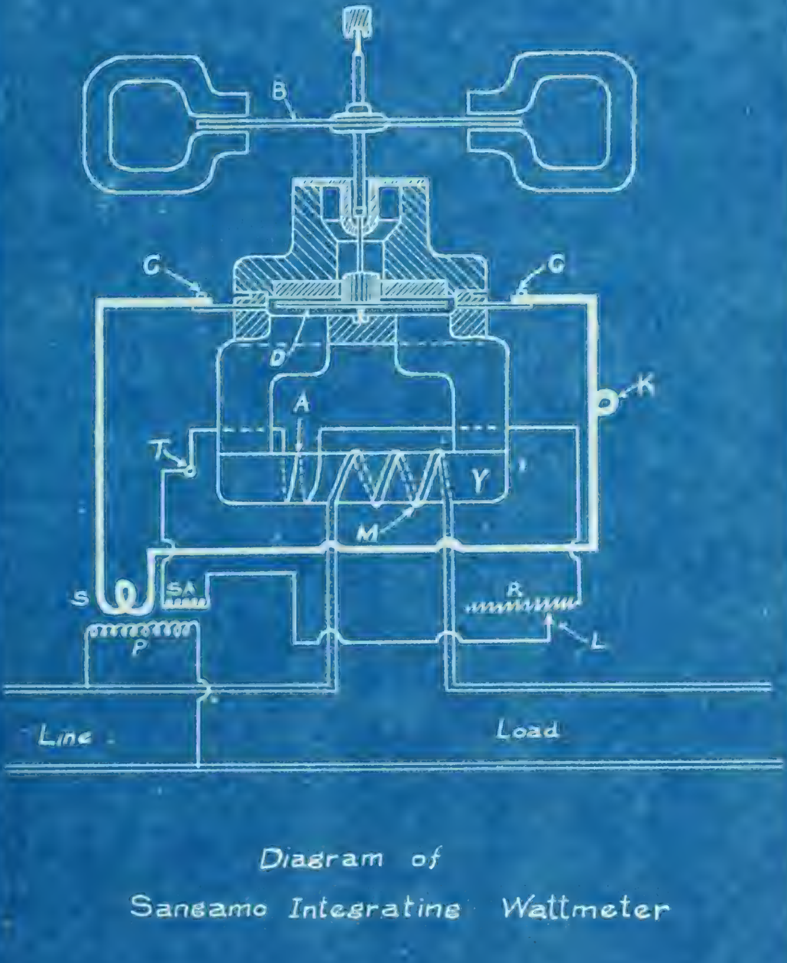


Diagram of
Sangamo Integrating Wattmeter

sure to the armature (D). The terminals of the secondary (S) of the small transformer are led into the mercury cup through the clips (C C). On account of the hysteresis of the iron, there is a slight lag in the magnetic field produced by the series coil (M). Therefore a corresponding lag has to be given to the current through the armature, and this is done by means of the coils (K) in the secondary circuit. The light load adjustment is obtained by means of a small auxiliary transformer secondary (SA). One lead of this auxiliary secondary connects with the terminal (T) as does also one terminal of the small starting coil (A) which is wound on top of the series coil (M). The other end of the starting coil (A) is connected to the adjustable resistance (R). The other terminal of the auxiliary secondary is connected to the sliding contact (L). The current through the coil (A) gives a weak field for starting, and this field can be adjusted to any desired value by means of the variable resistance (R). The secondary (S) furnishes to the armature a current of large volume proportional to the impressed electromotive force of the circuit. This current remains in phase with the pressure, and the secondary is so connected that the current through the armature will be in phase with the main current. This can be shown by means of the vector diagrams given below.

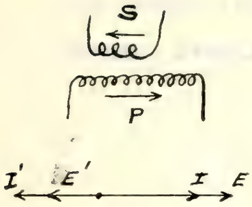


Fig.1

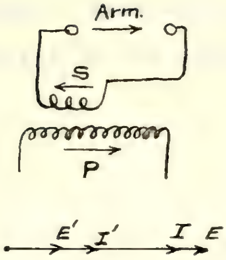


Fig.2

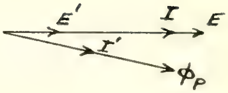


Fig.3

Let E and E' be the e.m.f.s of the primary and secondary coils of the small transformer, and let I and I' be the currents. E' and I' are in phase and are displaced from E and I by 180° as shown in Fig.1. The secondary coil (S), however, is connected so that E' and I' through the armature are in phase with E and I as shown in Fig.2. The hysteresis in the iron causes the series flux (ϕ_p) to lag slightly behind the pressure and consequently the current through the armature is given a corresponding lag by means of the coil (K). Then the conditions are represented by Fig.3. The above diagrams are for a non-inductive load. The torque varies directly as the product of the secondary current by the primary flux times the cosine of the angle between them, i.e. $T \propto I' \phi_p \text{ Cos } \theta$. Therefore it can be seen that the meter will register true energy for all power factors, since on an inductive load the actual lag between

the current through the armature and the magnetism in the series yoke will be the same as the lag in the load current itself.

DATA and CURVES OF TESTS

FORT WAYNE METER

FORT WAYNE METER #452568.

Data for the determination of the quadrature relation between the series and pressure fluxes.

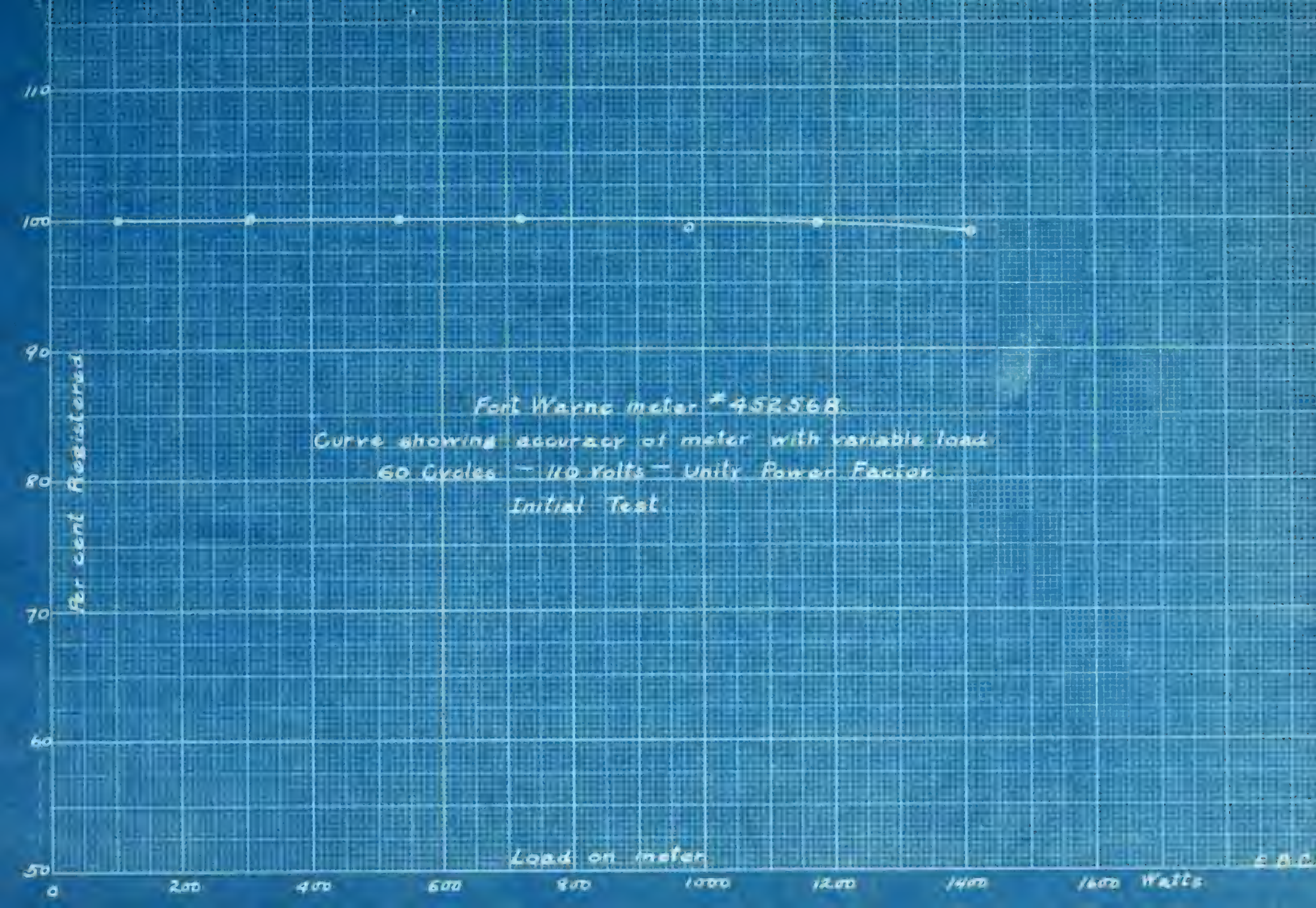
E.	I.	EI.	Watts.	Cos Ø.	Ø.
10.9	110	1199	13.5	.011259	89° 21′ 18″
10.6	110	1166	15.0	.012865	89° 15′ 46″
10.6	110	1166	14.5	.012436	89° 17′ 40″

The average value for the angle Ø is 89° 18′ 16″ This is so close to quadrature that there would be very little error introduced, except at low power factors.

FORT WAYNE METER #452568.

Data showing the effect of varying the load when the meter is operated at 110 volts, 60 cycles, and unity power factor. This is the initial calibration test.

Standard Watts.	Meter Watts.	R.	T.	%.
1410	1395	20	25.8	99
1175	1170	15	23.1	99.5
980	971	15	27.8	99.2
720	722	15	37.4	100.2
535	535	10	33.6	100
308	310	4	23.2	100.5
107	107	2	33.6	100



Fort Wayne meter # 452568.

Curve showing accuracy of meter with variable load.

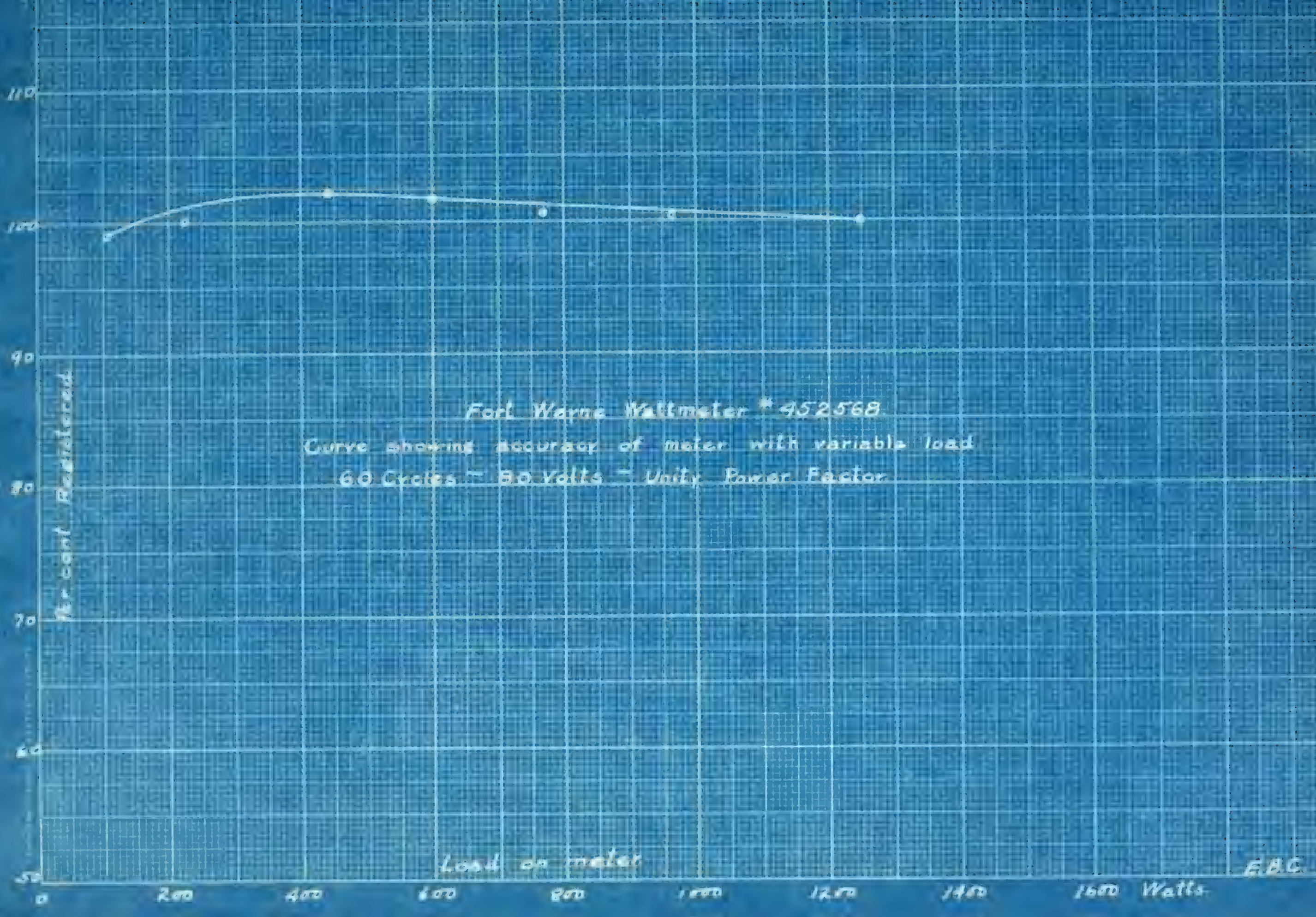
60 Cycles – 110 Volts – Unity Power Factor.

Initial Test.

FORT WAYNE METER #452568.

Data showing the effect of varying the load when the meter is operated at 80 volts, 60 cycles, and unity power factor.

Standard Watts.	Meter Watts.	R.	T.	%.
1250	1250	15	21.6	100
962	965	15	28	100.2
770	775	10	23.2	100.5
600	610	8	23.6	101.6
440	450	8	32	102.2
225	225	4	32	100
108	107	2	33.6	99.1



Fort Wayne Wattmeter * 452568

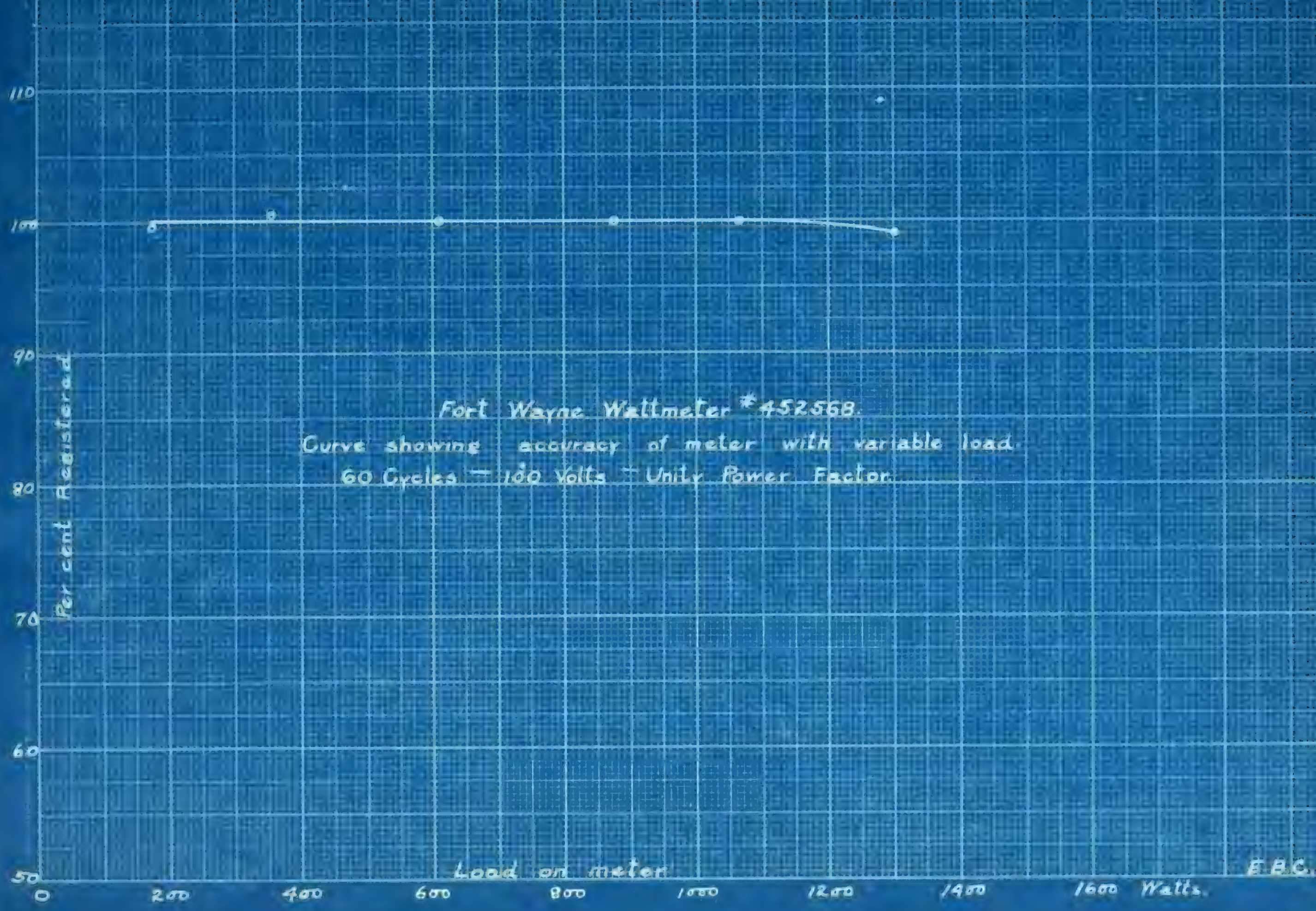
Curve showing accuracy of meter with variable load

60 Cycles – 80 Volts – Unity Power Factor

FORT WAYNE METER #452568.

Data showing the effect of varying the load when the meter is operated at 100 volts, 60 cycles, and unity power factor.

Standard Watts.	Meter Watts.	R.	T.	%.
1300	1288	20	28	99
1065	1062	15	25.4	99.8
875	876	15	30.8	99.9
610	610	8	23.6	100
358	360	6	30	100.5
172	171	3	31.6	99.5



Fort Wayne Wattmeter #452568.

Curve showing accuracy of meter with variable load.

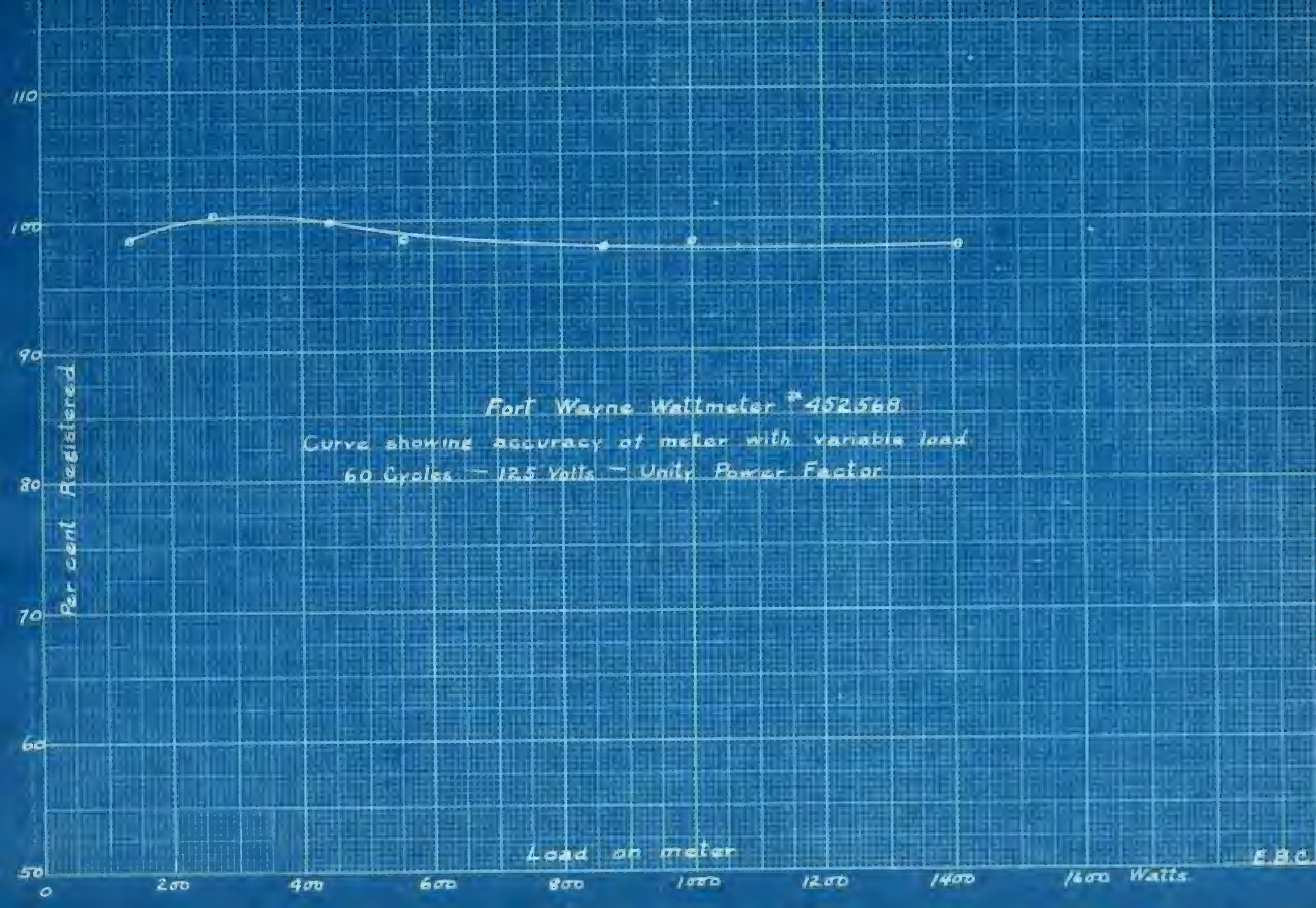
60 Cycles — 100 Volts — Unity Power Factor.

E.B.C.

FORT WAYNE METER #452568.

Data showing the effect of varying the load when the meter is operated at 125 volts, 60 cycles, and unity power factor.

Standard Watts.	Meter Watts.	R.	T.	%.
1410	1380	20	26.1	98
1000	985	15	27.4	98.5
865	845	15	32	97.8
558	550	8	26.2	98.5
440	439	6	24.6	99.9
265	266.5	4	27	100.5
137	135	2	26.7	98.6



Fort Wayne Wattmeter № 452568

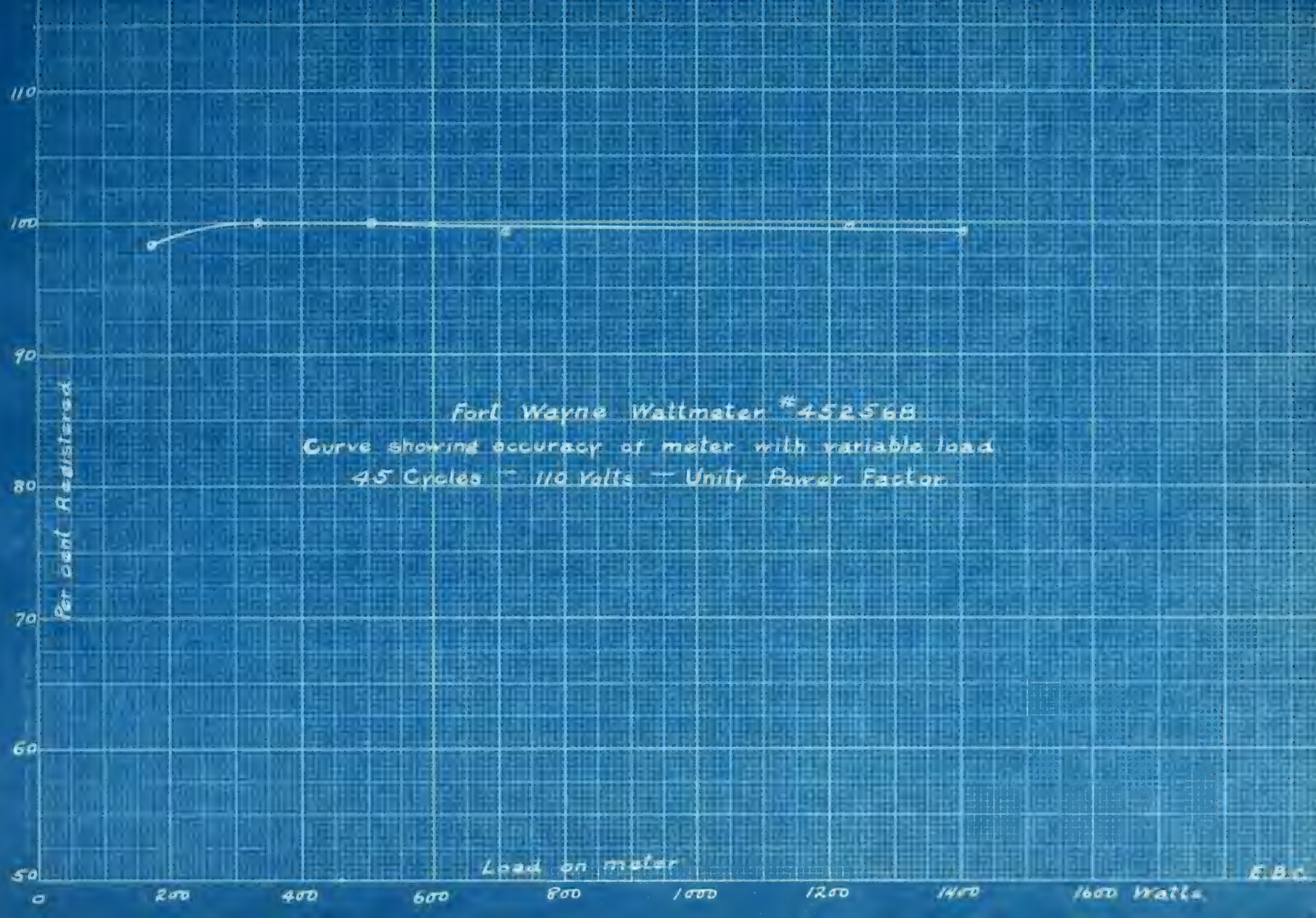
Curve showing accuracy of meter with variable load

60 Cycles — 125 Volts — Unity Power Factor

FORT WAYNE METER #452568.

Data showing the effect of varying the load when the meter is operated at 110 volts, 45 cycles, and unity power factor.

Standard Watts.	Meter Watts.	R.	T.	%.
1405	1395	20	25.8	99.4
1230	1228	20	29.3	99.8
710	704	15	38.4	99.2
505	505	6	21.4	100
335	336	8	42.8	100.2
173	170	2	21.2	98.4

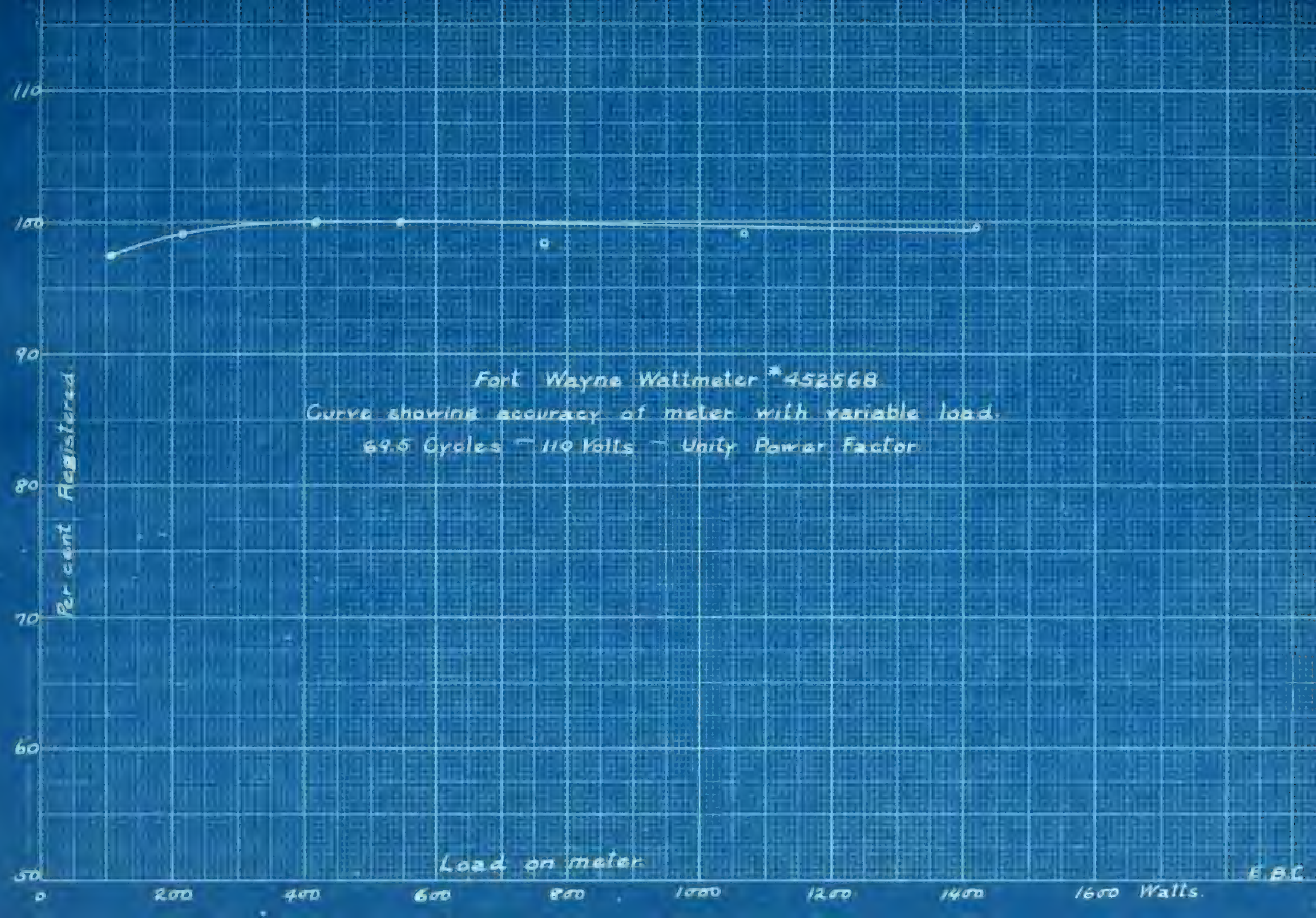


Fort Wayne Wattmeter #452568
Curve showing accuracy of meter with variable load
45 Cycles — 110 Volts — Unity Power Factor

FORT WAYNE METER #452568.

Data showing the effect of varying the load when the meter is operated at 110 volts, 69.5 cycles and unity power factor.

Standard Watts.	Meter Watts.	R.	T.	%.
1420	1418	20	25.4	99.8
1065	1055	15	25.6	99
765	750	10	24	98.2
545	545	8	26.4	100
417	417	5	21.6	100
212	210	4	34.2	99.1
107	104.3	2	34.5	97.5



Fort Wayne Wattmeter #452568

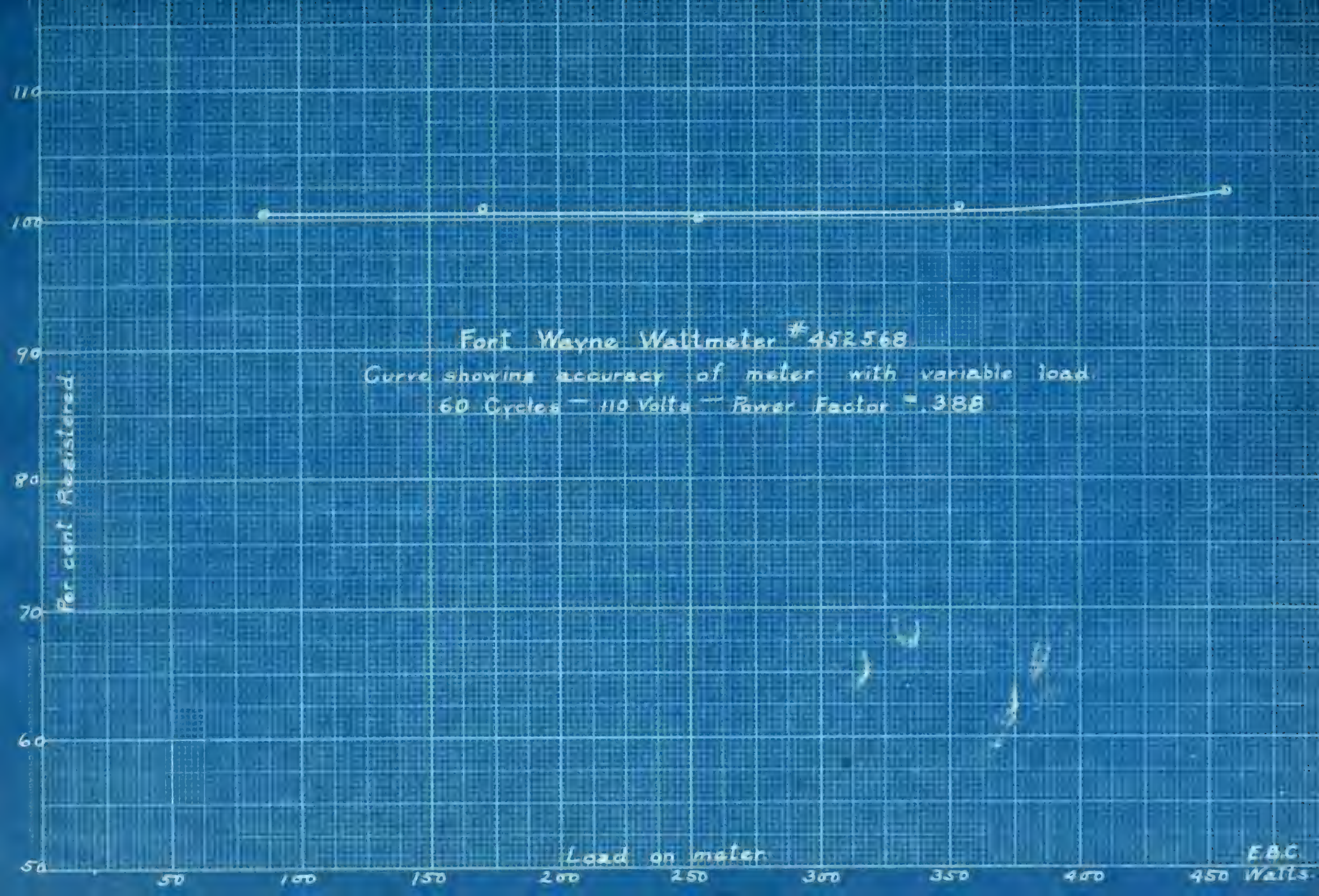
Curve showing accuracy of meter with variable load.

69.5 Cycles — 110 Volts — Unity Power Factor

FORT WAYNE METER #452568.

Data showing the effect of varying the load when the meter is operated at 110 volts, 60 cycles, and a power factor of .388.

Standard Watts.	Meter Watts.	R.	T.	%.
457	467	8	30.8	102
354	357	5	25.2	101
253	253	4	28.4	100
171	173	2	20.8	101
85.5	86.0	2	41.8	100.5



Fort Wayne Wattmeter #452568

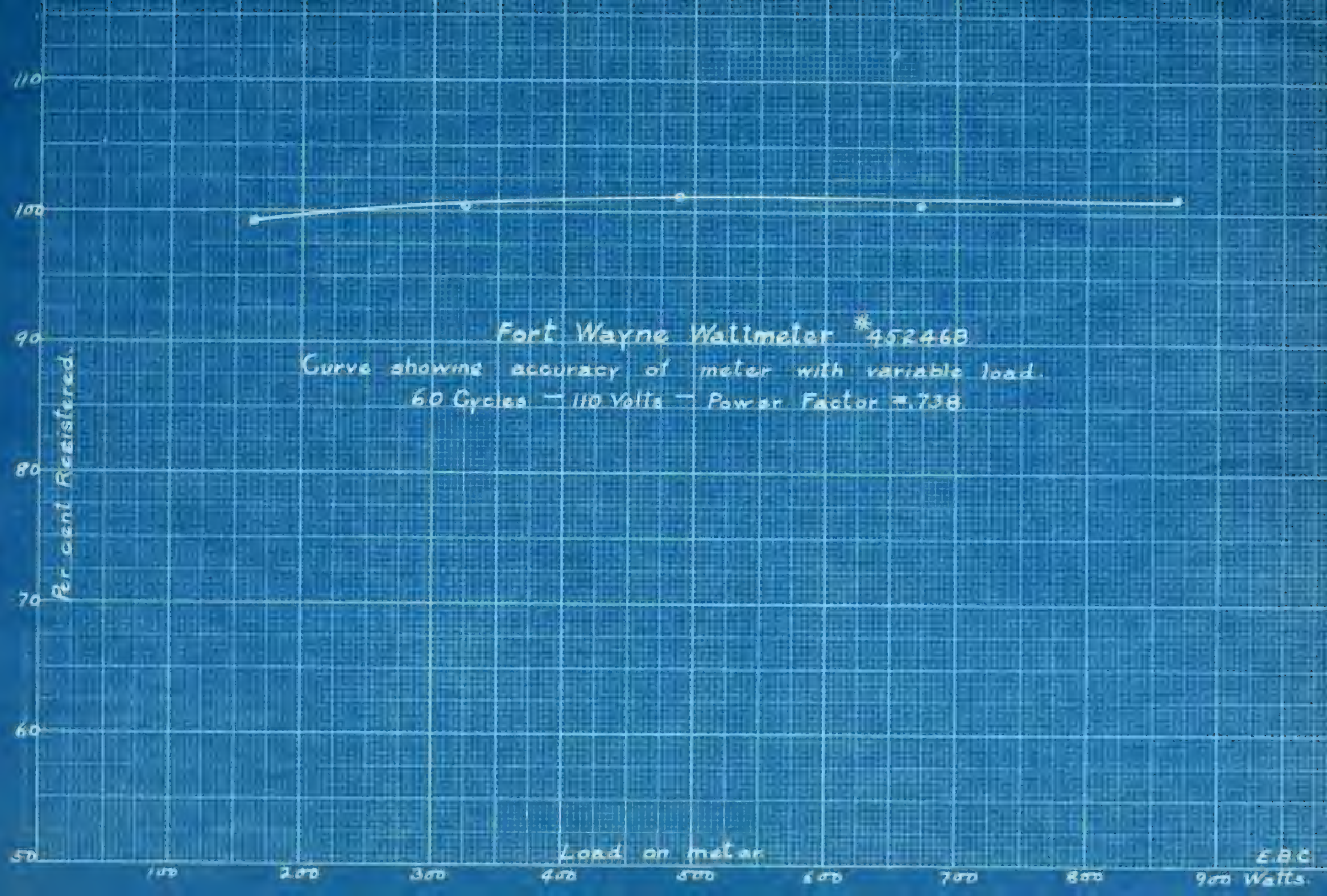
Curve showing accuracy of meter with variable load

60 Cycles — 110 Volts — Power Factor = .388

FORT WAYNE METER #452568.

Data showing the effect of varying the load when the meter is operated at 110 volts, 60 cycles, and a power factor of .738.

Standard Watts	Meter Watts.	R.	T.	%.
867	877	15	30.8	101.1
673	677	10	26.6	100.5
487	493	8	29.2	101.2
325	326	4	22.1	100.2
162.5	161.2	2	22.3	99.3



Fort Wayne Wattmeter #452468

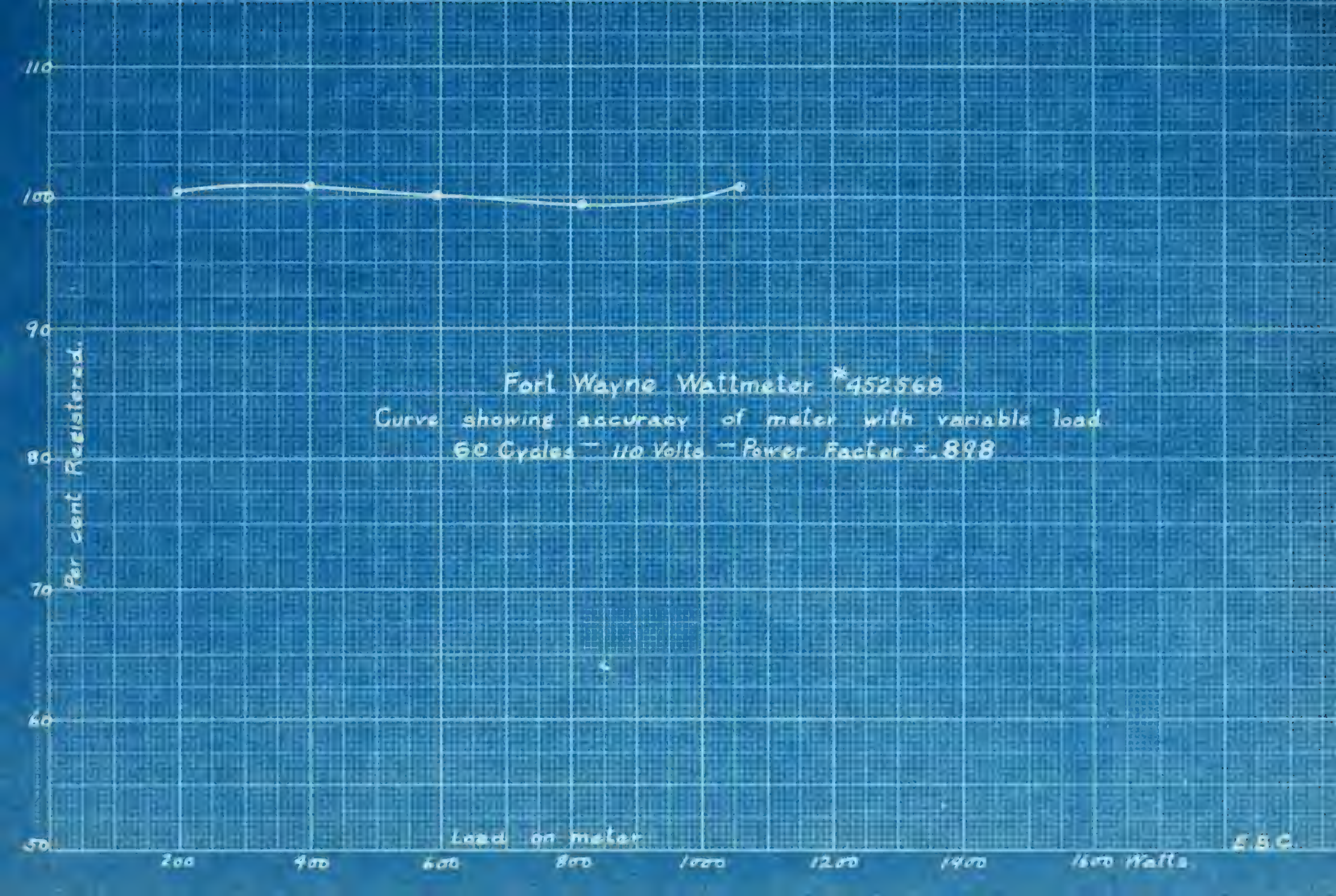
Curve showing accuracy of meter with variable load.

60 Cycles — 110 Volts — Power Factor =.738

FORT WAYNE METER #452568.

Data showing the effect of varying the load when the meter is operated at 110 volts, 60 cycles, and a power factor of .898.

Standard Watts.	Meter Watts.	R.	T.	%.
1055	1062	15	25.4	100.8
819	815	10	22.1	99.5
592	593	8	24.3	100.1
395	398	8	36.2	100.8
198	199	4	36.2	100.6

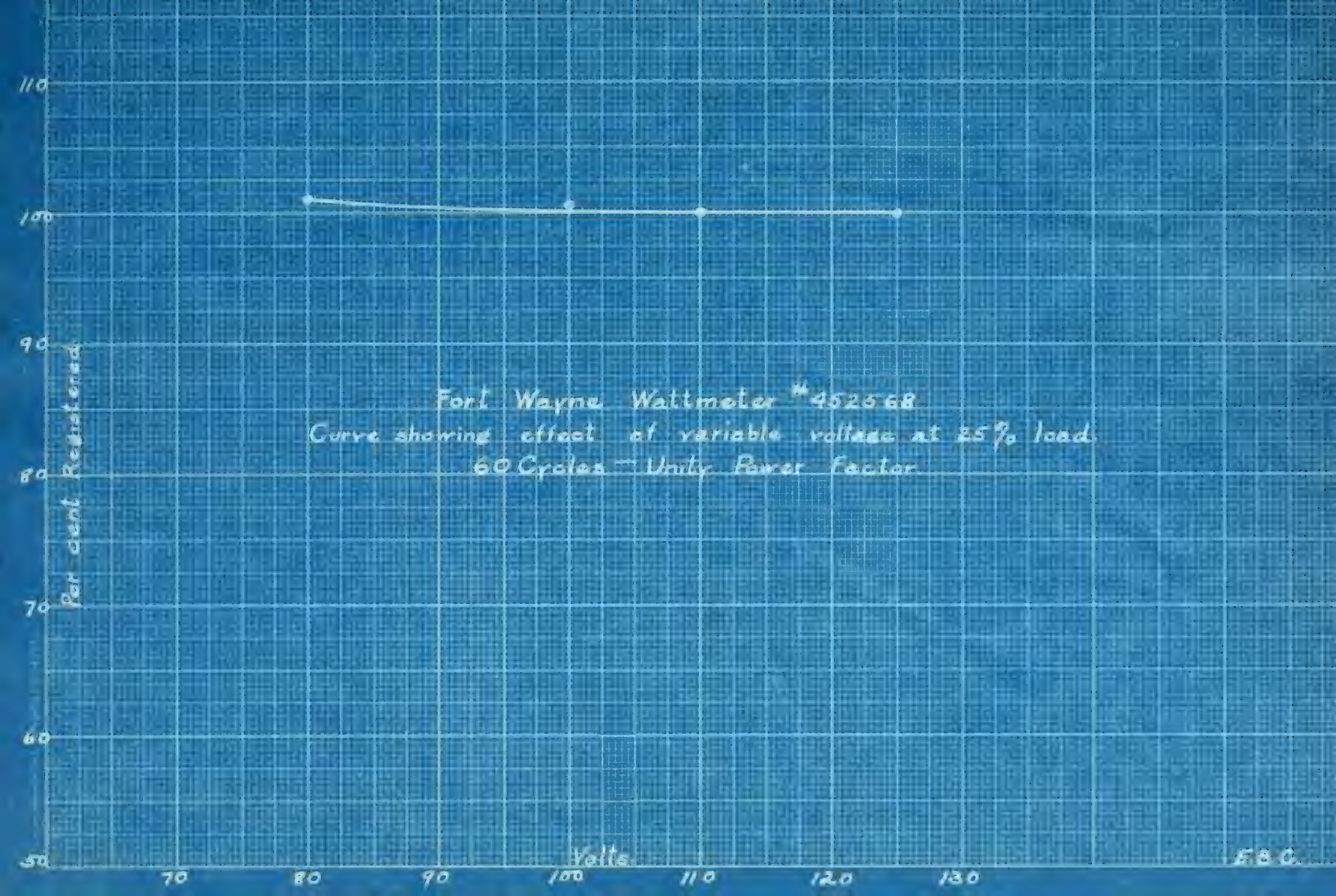


Fort Wayne Wattmeter #452568
Curve showing accuracy of meter with variable load
60 Cycles — 110 Volts — Power Factor = .898

FORT WAYNE METER #452568.

Data showing the effect of varying the voltage when the meter is operated at 110 volts, 60 cycles, and 25% load.

Standard Watts.	Meter Watts.	R.	T.	%	E.
275	278	4	25.9	101	80
275	277	4	26.0	100.7	100
275	275	4	26.2	100	110
275	275	4	26.2	100	125

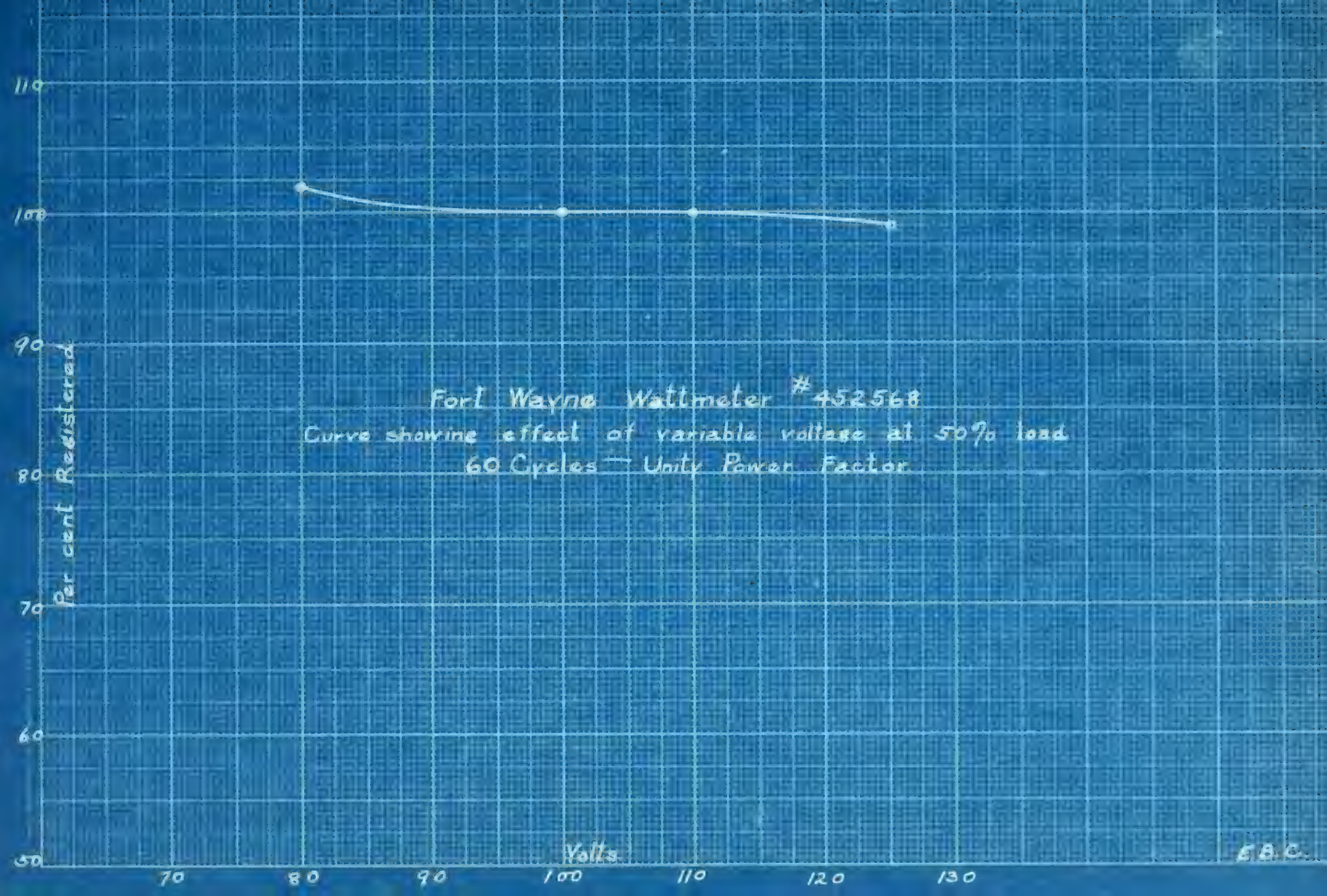


Fort Wayne Wattmeter #452568
Curve showing effect of variable voltage at 25% load
60 Cycles — Unity Power Factor

FORT WAYNE METER # 452568.

Data showing the effect of varying the voltage when the meter is operated at 110 volts, 60 cycles, and 50% load.

Standard Watts.	Meter Watts.	R.	T.	%.	E.
550	561	8	25.7	102	80
550	550	8	26.2	100	100
550	550	8	26.2	100	110
550	545	8	26.4	99	125

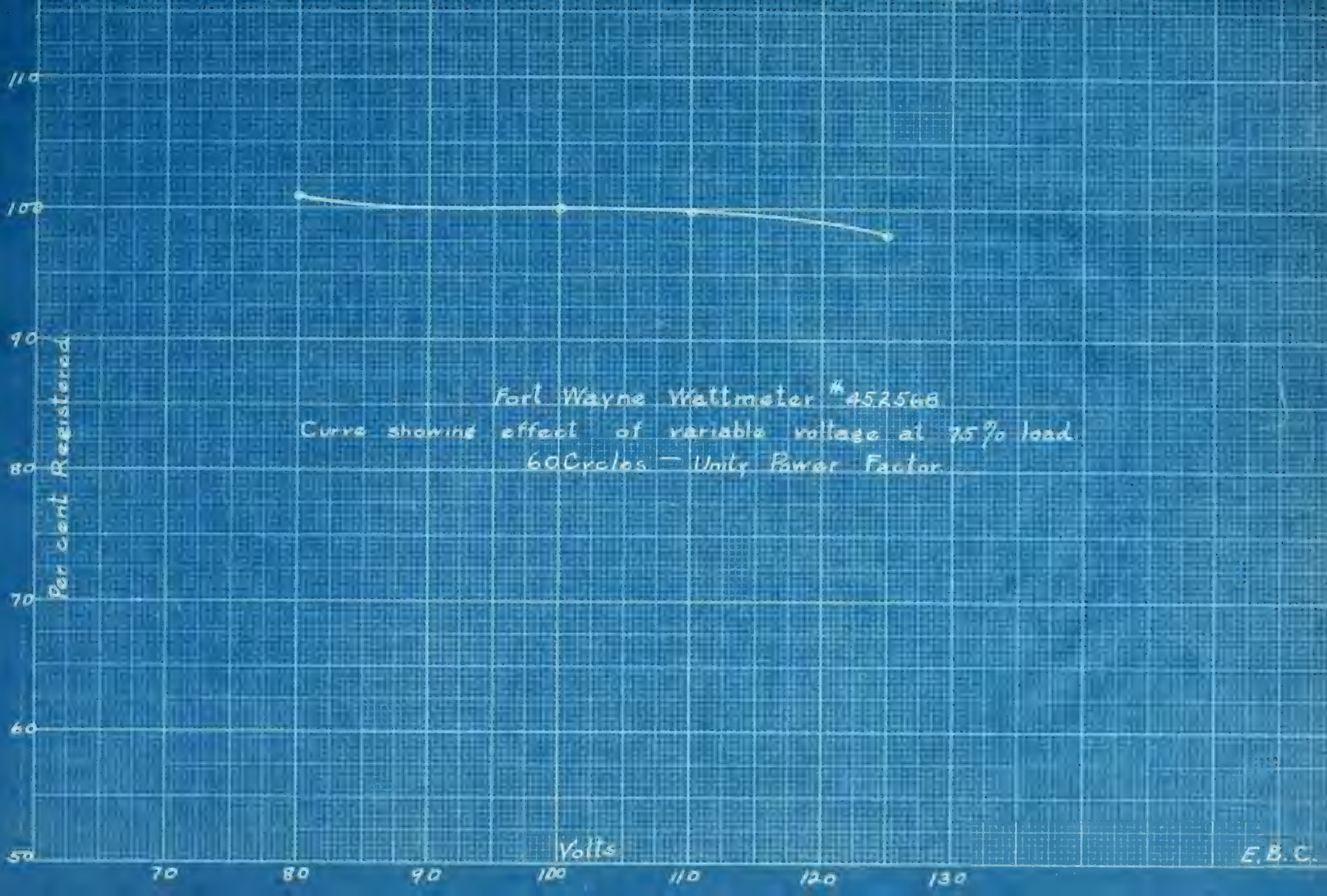


Fort Wayne Wattmeter #452568
Curve showing effect of variable voltage at 50% load
60 Cycles — Unity Power Factor

FORT WAYNE METER #452568.

Data showing the effect of varying the voltage when the meter is operated at 110 volts, 60 cycles, and 75% load.

Standard Watts.	Meter Watts.	R.	T.	%.	E.
825	833	15	32.4	101	80
825	825	15	32.7	100	100
825	823	15	32.8	99.8	110
825	808	15	33.4	98.0	125

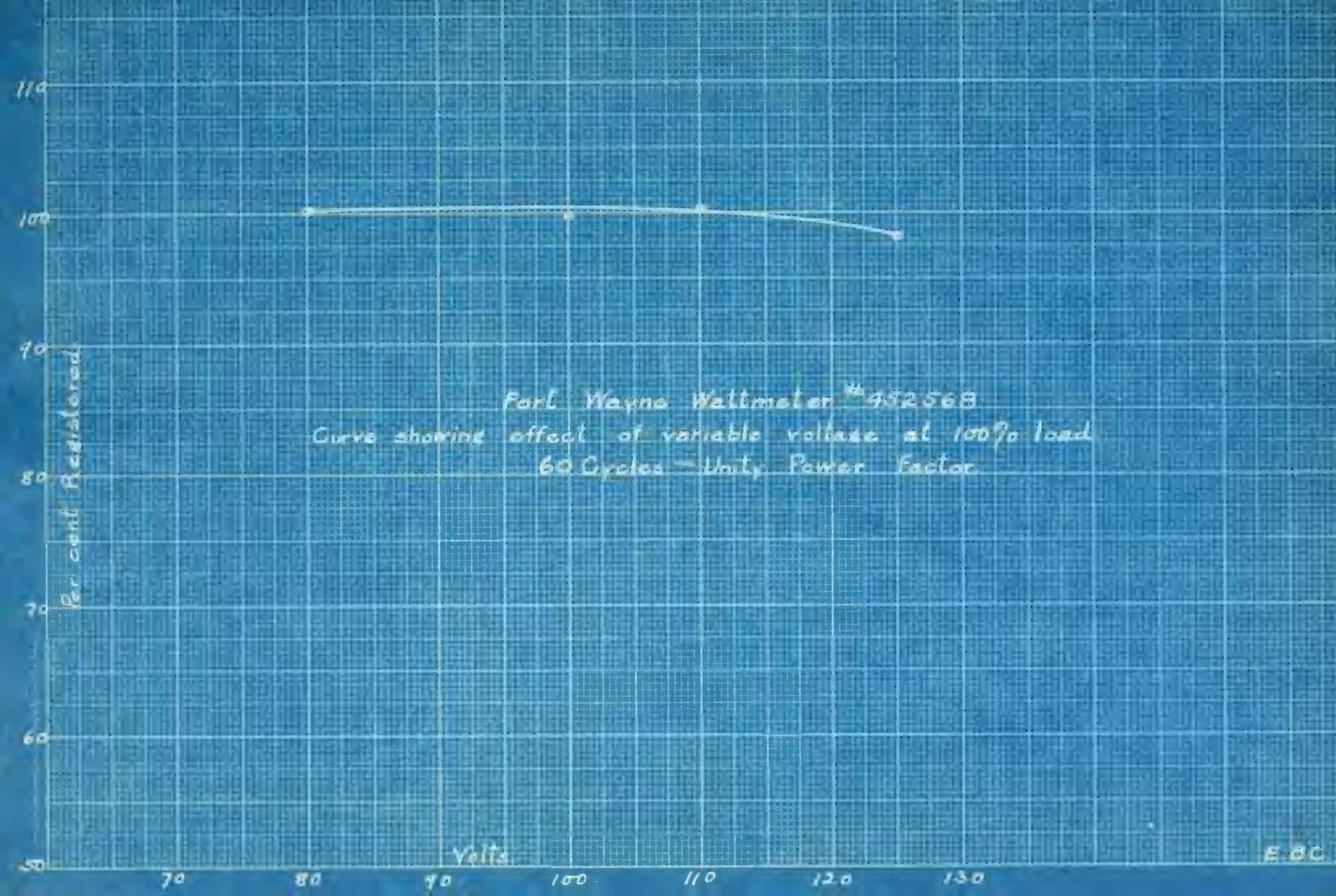


Fort Wayne Wattmeter #452566
Curve showing effect of variable voltage at 75% load
60 Cycles — Unity Power Factor

FORT WAYNE METER #452568.

Standard Watts.	Meter Watts.	R.	T.	%.	E.
1100	1102	15	24.5	100.2	80
1100	1098	15	24.6	99.8	100
1100	1105	15	24.4	100.4	110
1100	1080	15	25.0	98.2	125

Data showing the effect of varying the voltage when the meter is operated at 110 volts, 60 cycles, and 100% load.

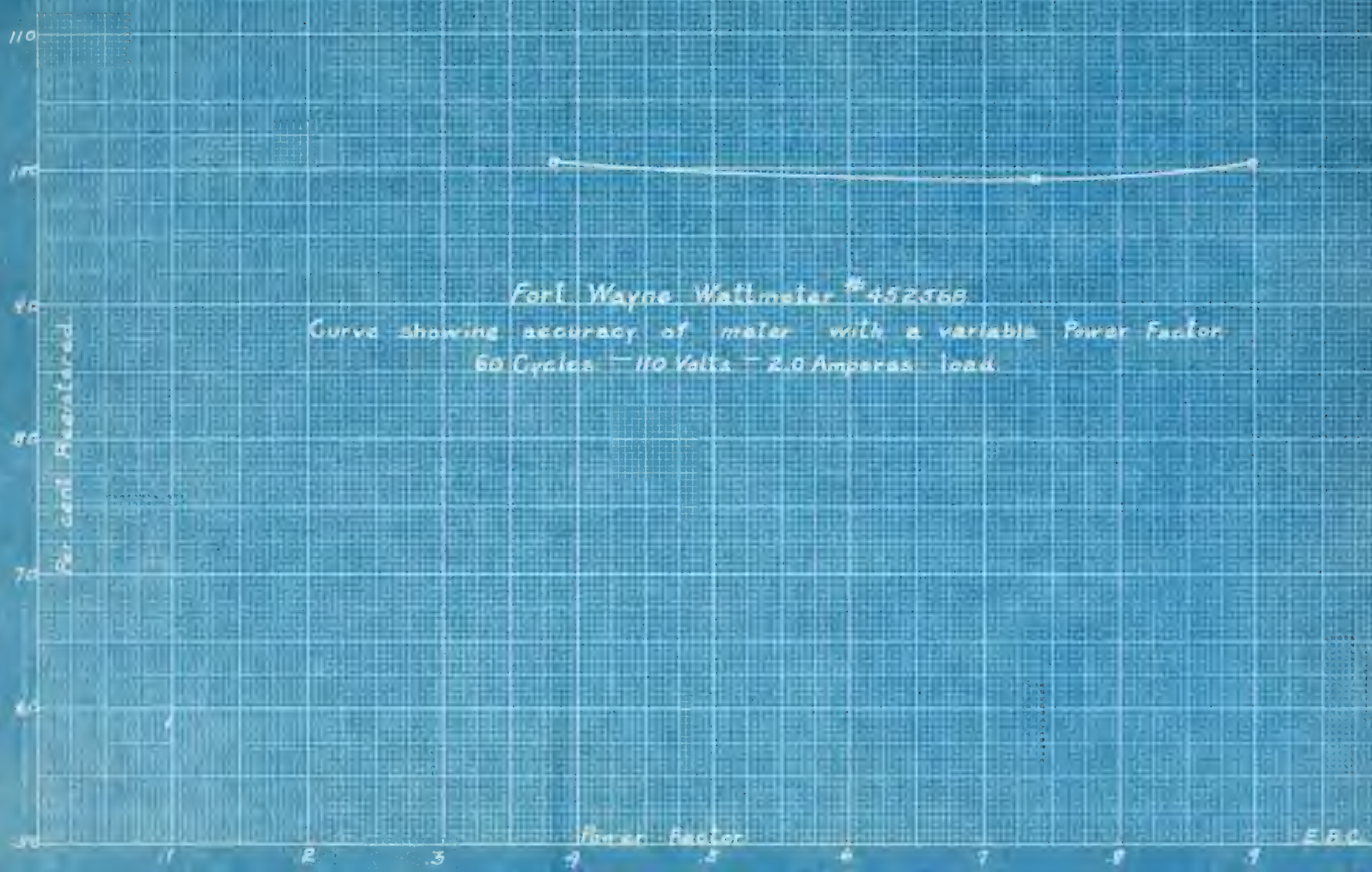


Fort Wayne Wattmeter #452568
Curve showing effect of variable voltage at 100% load
60 Cycles — Unity Power Factor

FORT WAYNE METER #452568.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles and a load of 2.0 amperes.

Standard Watts.	Meter Watts.	R.	T.	%.	Power Factor.
85.5	86.0	2	41.8	100.5	.388
162.5	161.2	2	22.8	99.3	.738
198	199	4	36.2	100.5	.898



Fort Wayne Wattmeter #452568.

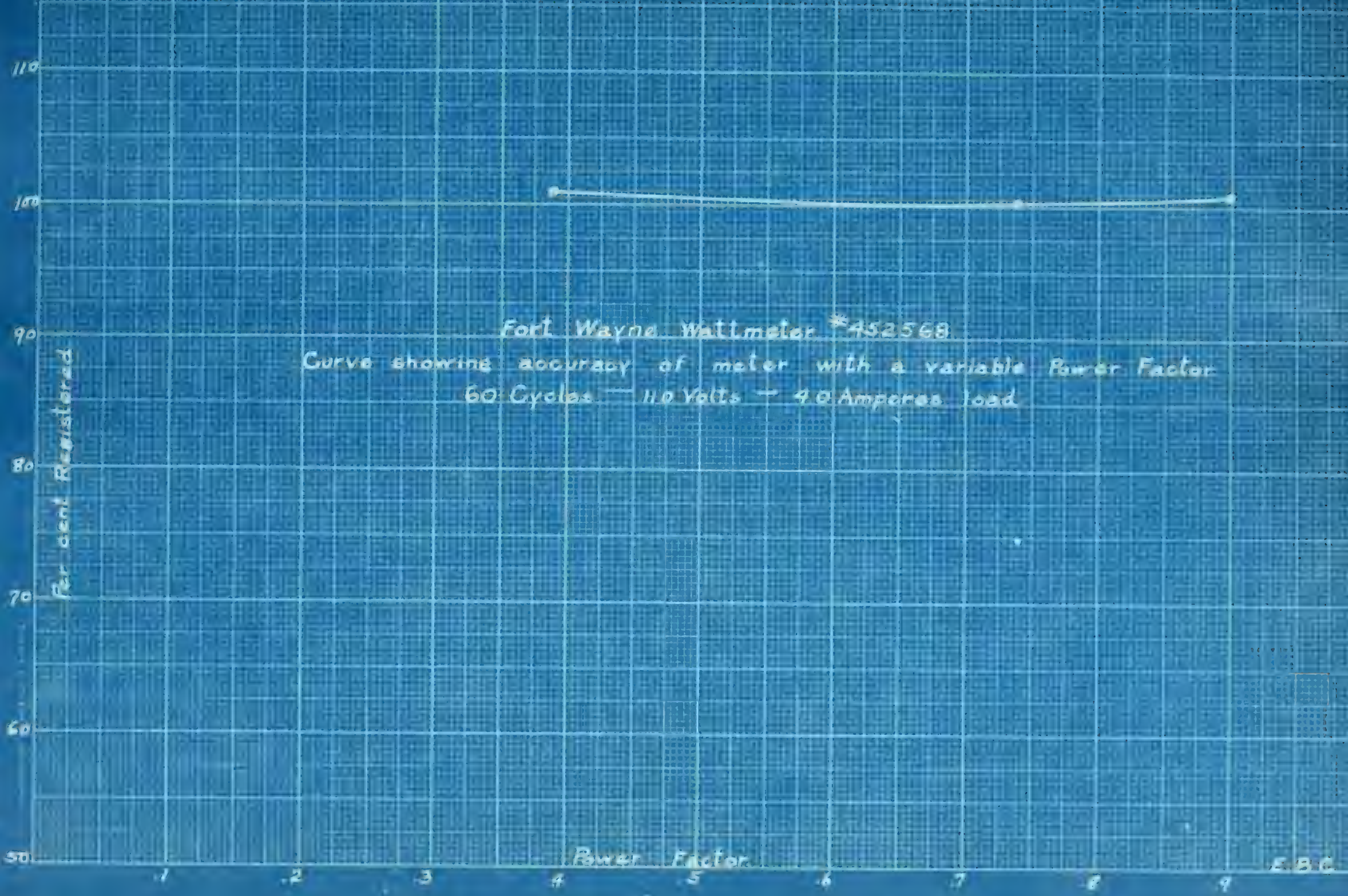
Curve showing accuracy of meter with a variable Power Factor

60 Cycles – 110 Volts – 2.0 Amperes load.

FORT WAYNE METER #452568.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles and a load of 4.0 amperes.

Standard Watts.	Meter Watts.	R.	T.	%.	Power Factor.
171	173	2	20.8	101	.388
325	326	4	22.1	100.2	.738
395	398	8	36.2	100.8	.898



Fort Wayne Wattmeter #452568

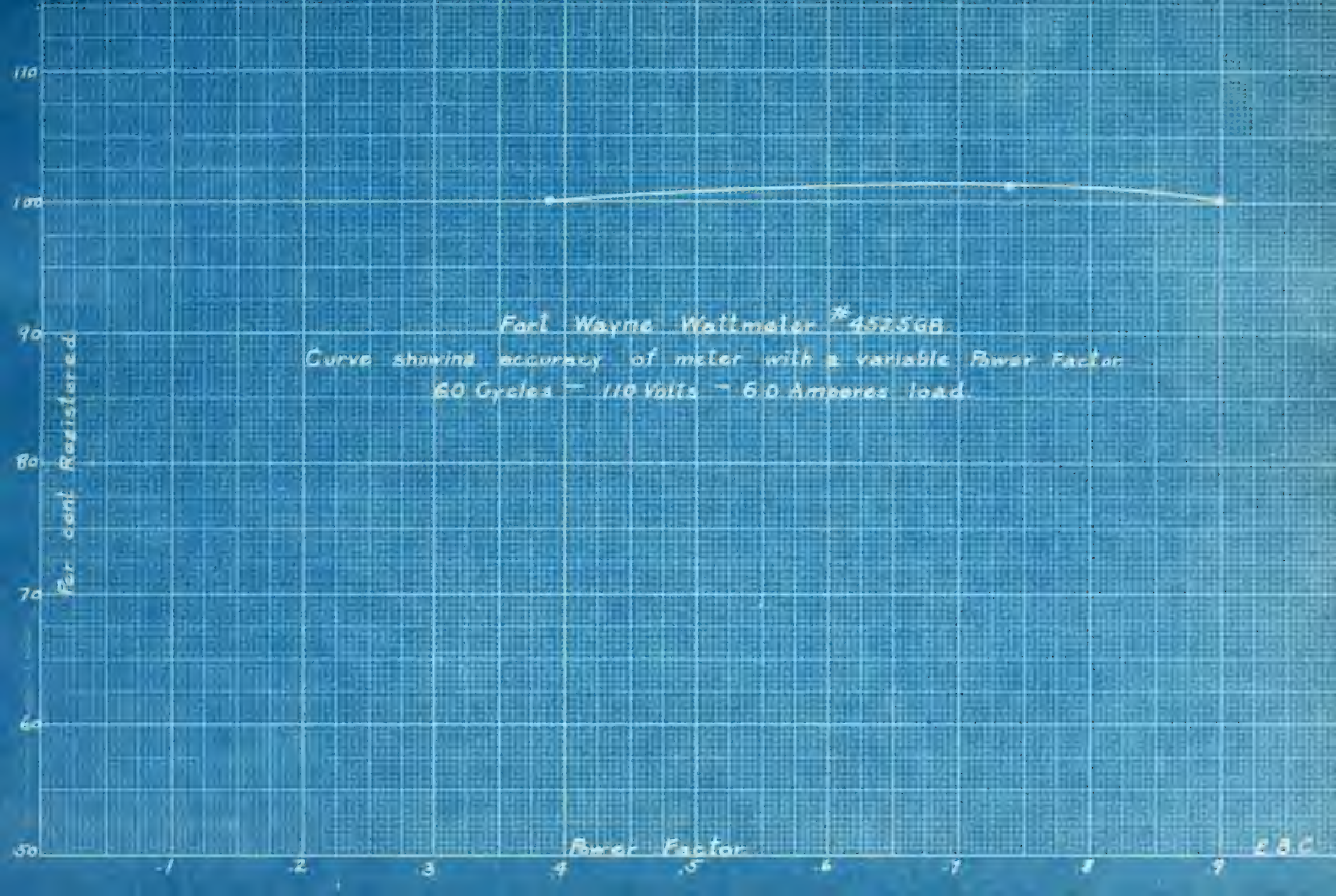
Curve showing accuracy of meter with a variable Power Factor

60 Cycles — 110 Volts — 40 Amperes load

FORT WAYNE METER #452568.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles and a load of 6.0 amperes.

Standard Watts.	Meter Watts.	R.	T.	%.	Power Factor.
253	253	4	28.4	100	.388
487	493	8	29.2	101.2	.738
592	593	8	24.3	100.1	.898



Fort Wayne Wattmeter #452568

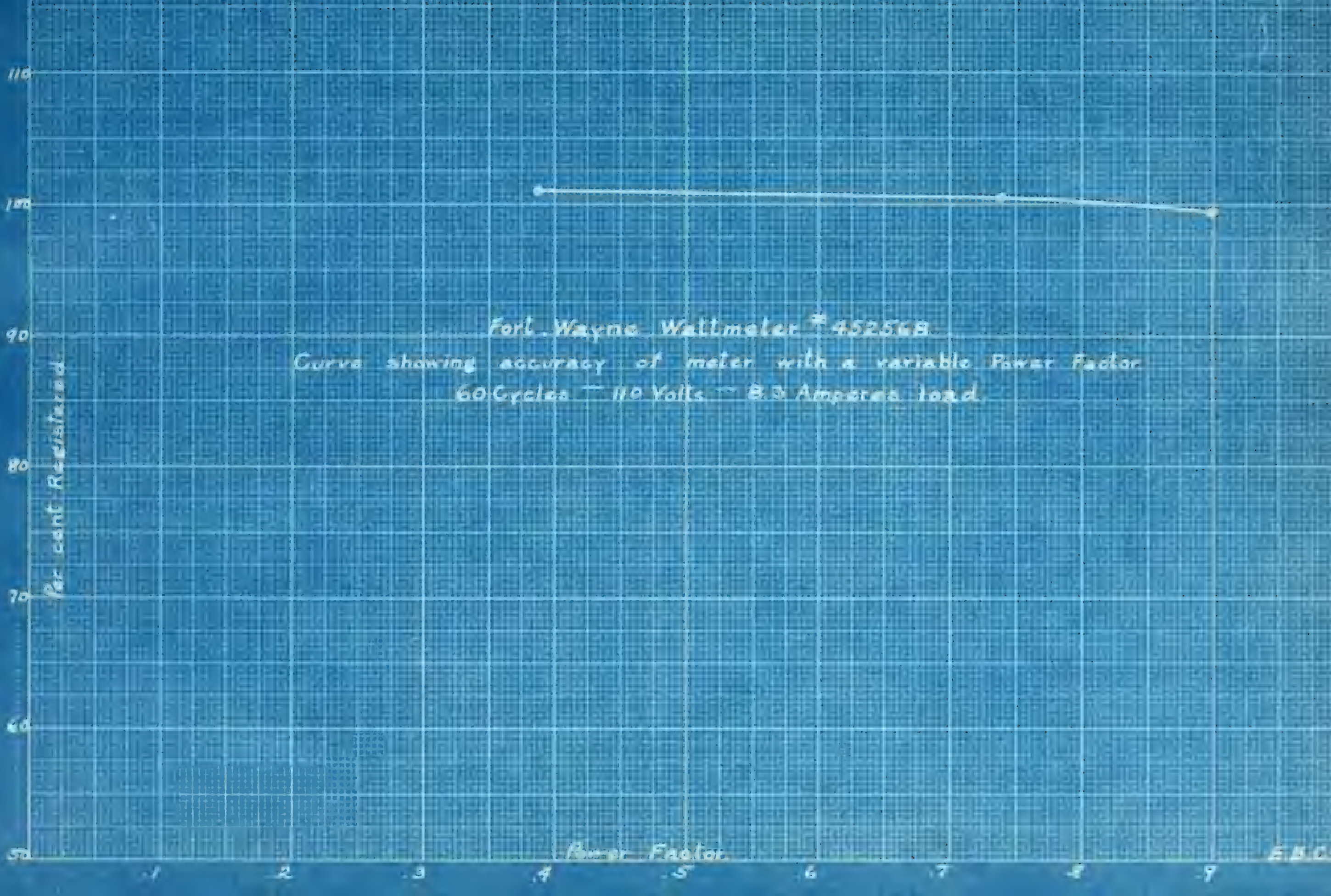
Curve showing accuracy of meter with a variable Power Factor

60 Cycles — 110 Volts — 6.0 Amperes load.

FORT WAYNE METER #452568.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles and a load of 8.3 amperes.

Standard Watts.	Meter Watts.	R.	T.	%.	power Factor.
354	357	5	25.2	101	.388
673	677	10	26.6	100.5	.738
819	815	10	22.1	99.5	.898

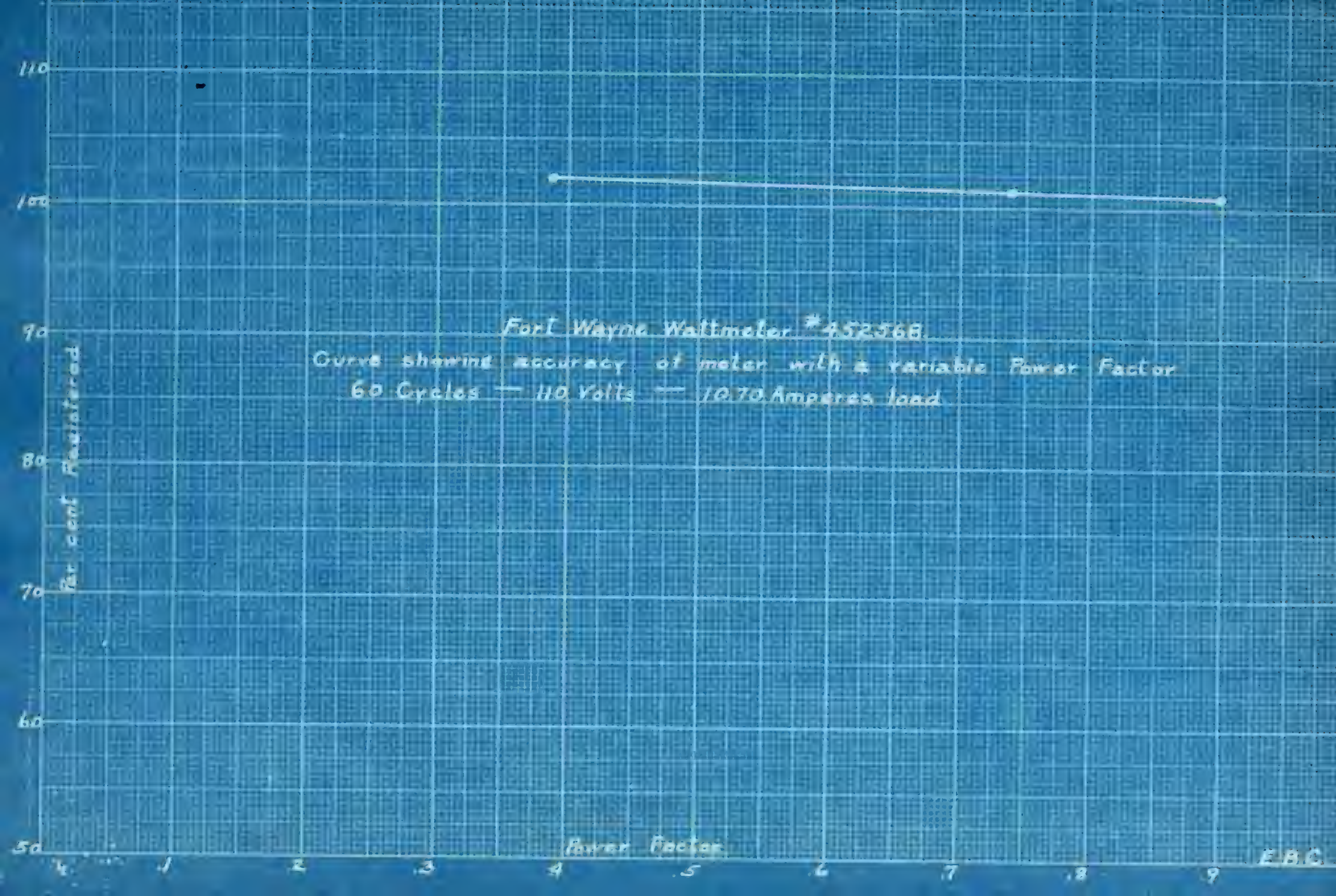


Fort. Wayne Wattmeter # 452568.
Curve showing accuracy of meter with a variable Power Factor
60 Cycles — 110 Volts — 8.3 Amperes load

FORT WAYNE METER #452568.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles and a load of 10.7 amperes.

Standard Watts.	Meter Watts.	R.	T.	%.	Power Factor.
457	467	8	30.8	10.2	.388
867	877	15	30.8	101.1	.738
1055	1062	15	25.4	100.8	.898



Fort Wayne Wattmeter #452568.

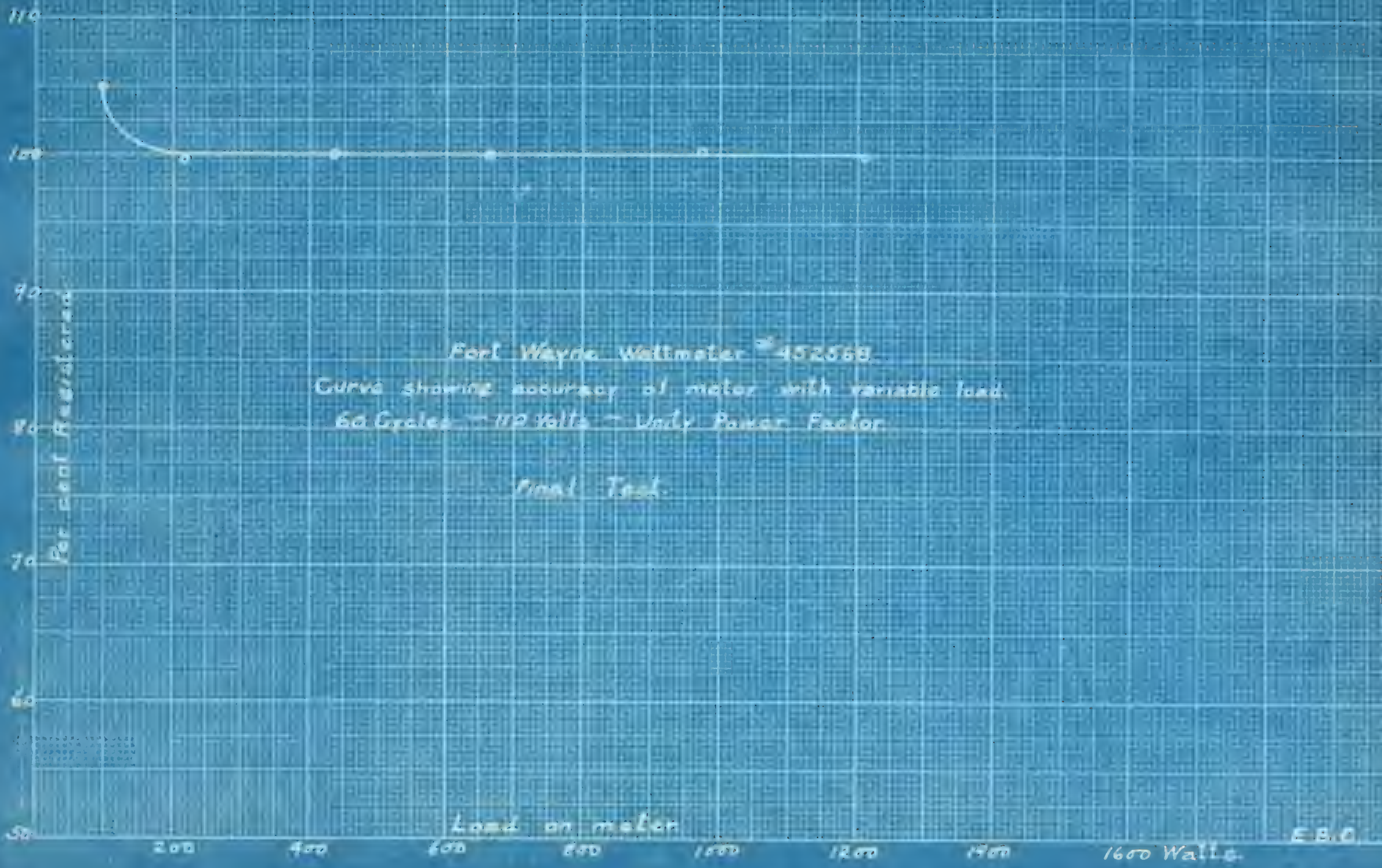
Curve showing accuracy of meter with a variable Power Factor

60 Cycles — 110 Volts — 10.70 Amperes load

FORT WAYNE METER #452568.

Data showing the accuracy of the meter when operated under normal conditions, namely, 110 volts, 60 cycles, variable load. This was the second test under normal conditions, and was made after the completion of all of the other tests in order to ckeck up with the initial calibration test.

Standard Watts.	Meter Watts.	R.	T.	%.
1210	1208	20	29.8	99.8
970	971	15	27.8	100.1
663	661	8	21.8	99.8
435	435	6	24.8	100
215	214	3	25.2	99.5
96.3	101	2	35.6	105



Fort Wayne Wattmeter # 452568.

Curve showing accuracy of meter with variable load.

60 Cycles — 110 Volts — Unity Power Factor.

Final Test.

SANGAMO METER

SANGAMO METER #76671.

Data for the determination of the phase relation between the series and pressure fields.

I.	E.	Watts.	EI.	Cos ø.	ø.
10.55	110	46	1160.5	.03964	87° 43' 42."
10.7	110	28	1177	.059893	86° 33' 58"
10.6	110	56	1166	.024014	88° 37' 26"

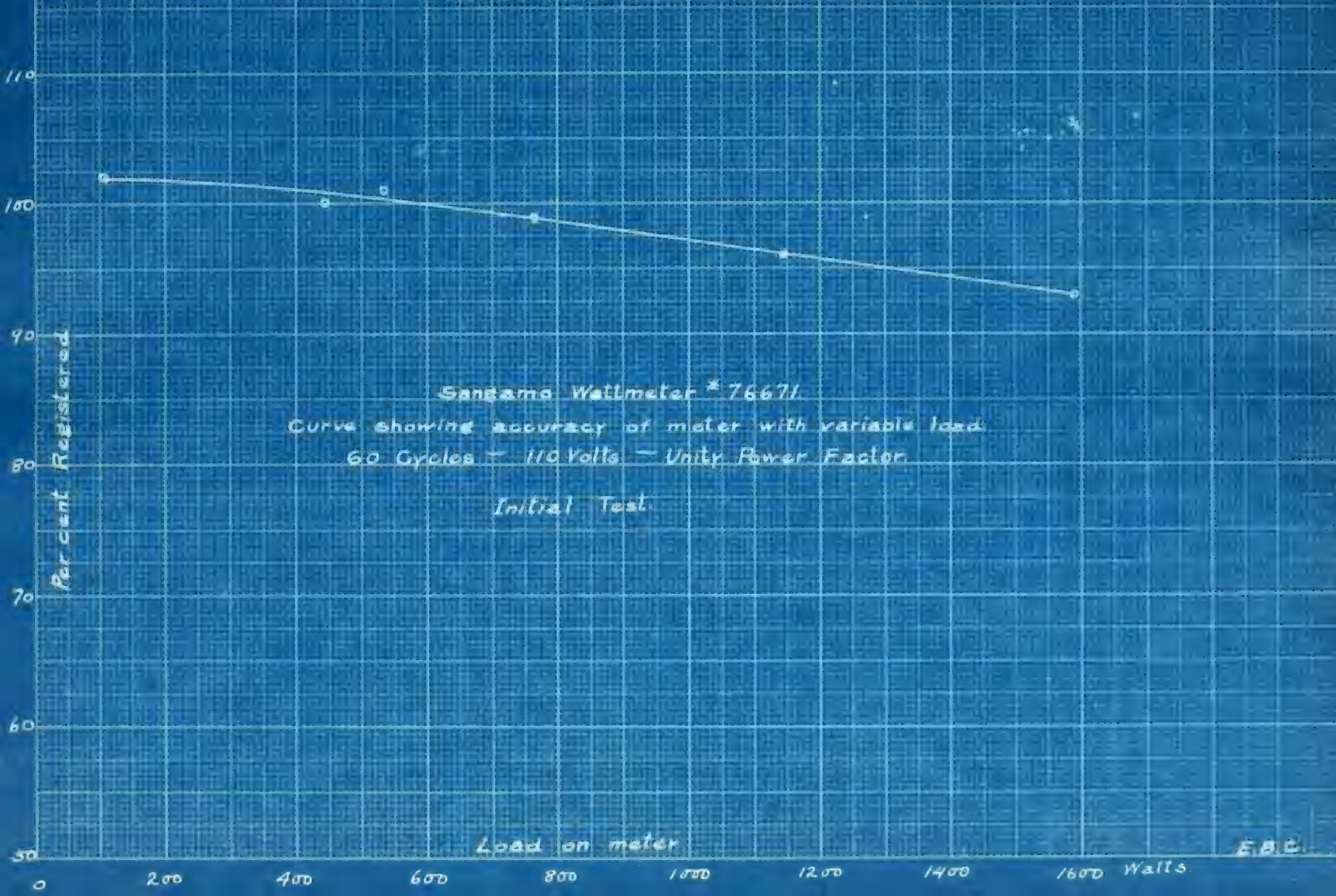
The readings in the first test were taken when the disc came to a standstill. In the second test, the disc was slowly revolving forward. In the third test the disc was revolving backward at hte same speed.

The average value for the angle ø is 87° 35' 42."

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 110 volts, 60 cycles, and unity power factor. This was the initial calibration test.

Standard Watts.	Meter Watts.	R.	T.	%.
1590	1488	20	24.2	93
1145	1100	15	24.5	96
765	756	10	23.8	98.8
535	541	10	44.4	101
443	443	6	24.4	100
108	110.3	2	32.6	102


Sangamo Wattmeter # 76671.

Curve showing accuracy of meter with variable load

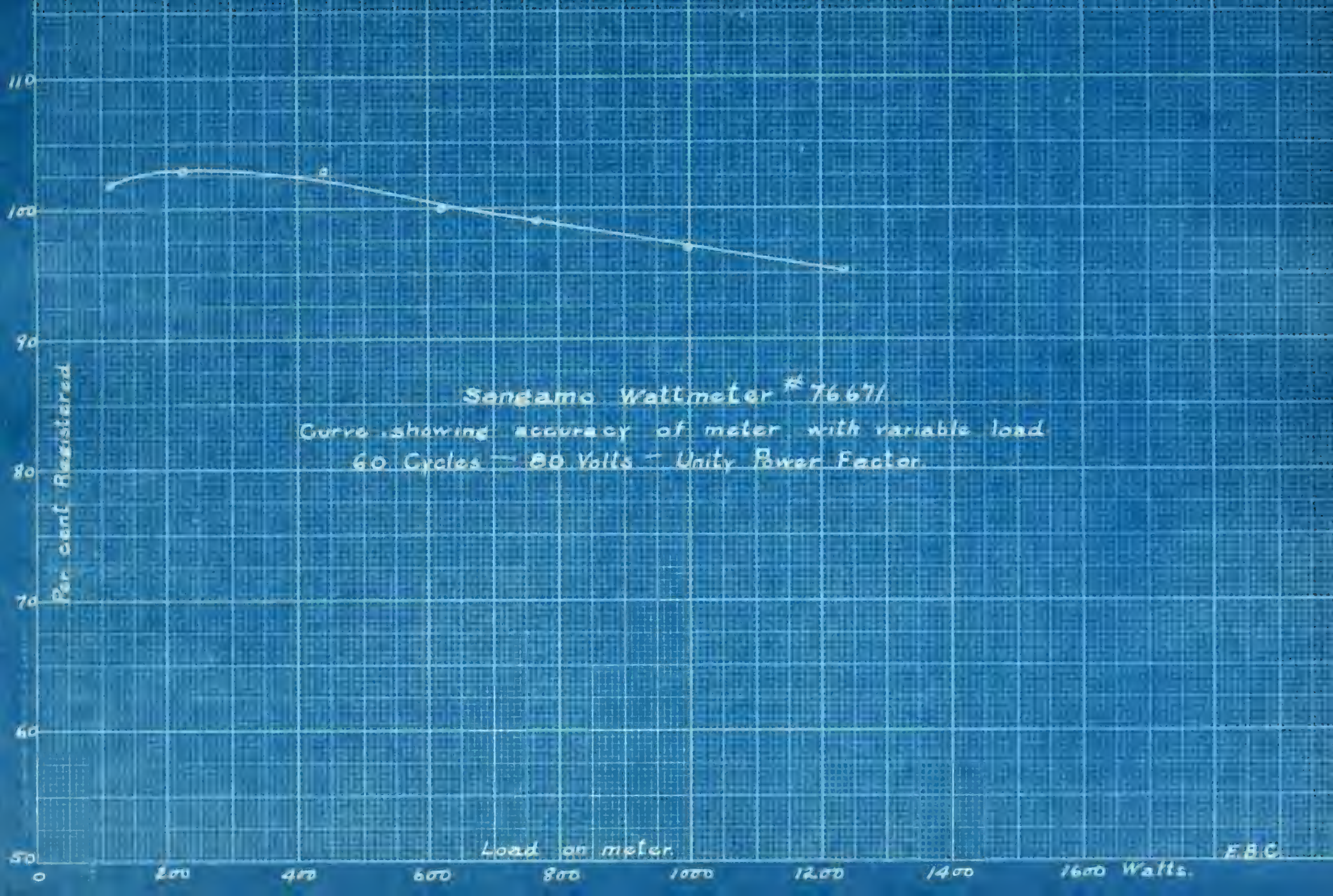
60 Cycles — 110 Volts — Unity Power Factor.

Initial Test.

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 80 volts, 60 cycles, and unity power factor.

Standard Watts.	Meter Watts.	R.	T.	%.	E.
1235	1175	15	23	95.1	80
995	965	15	28	97	80
765	757	10	23.8	99	80
615	615	8	23.4	100	80
440.	453	8	31.8	103	80
224	230	4	31.4	102.8	80
111	113	2	31.8	101.8	80



Sangamo Wattmeter # 76671

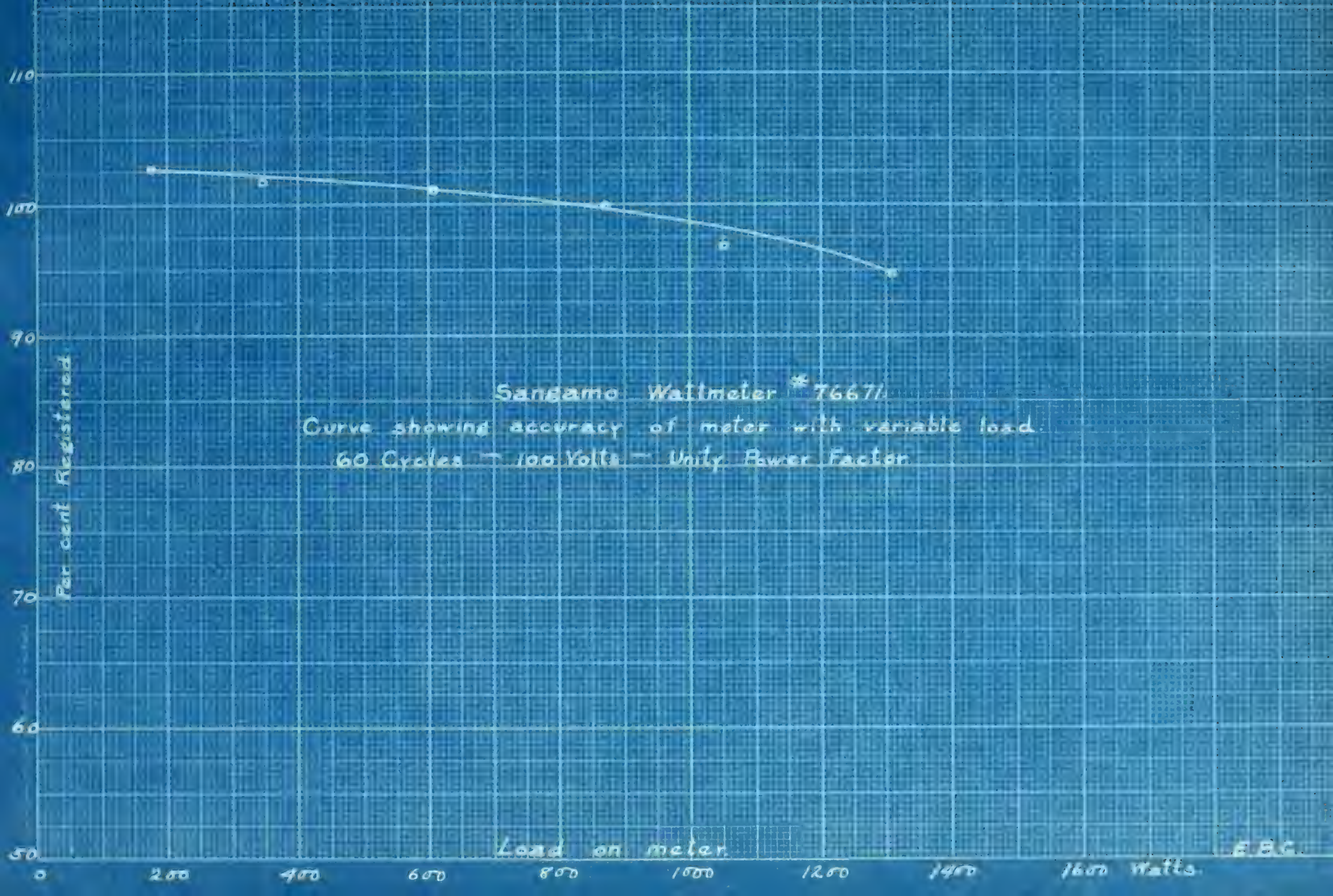
Curve showing accuracy of meter with variable load

60 Cycles — 80 Volts — Unity Power Factor

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 100 volts, 60 cycles, and unity power factor.

Standard	Meter	R.	T.	%.	E.
1310	1240	20	29	94.6	100
1050	1015	15	26.6	96.6	100
870	871	15	31	99.9	100
603	610	8	23.6	101	100
345	351	6	30.8	101.5	100
174	178.8	3	30.2	102.8	



Sangamo Wattmeter #76671.

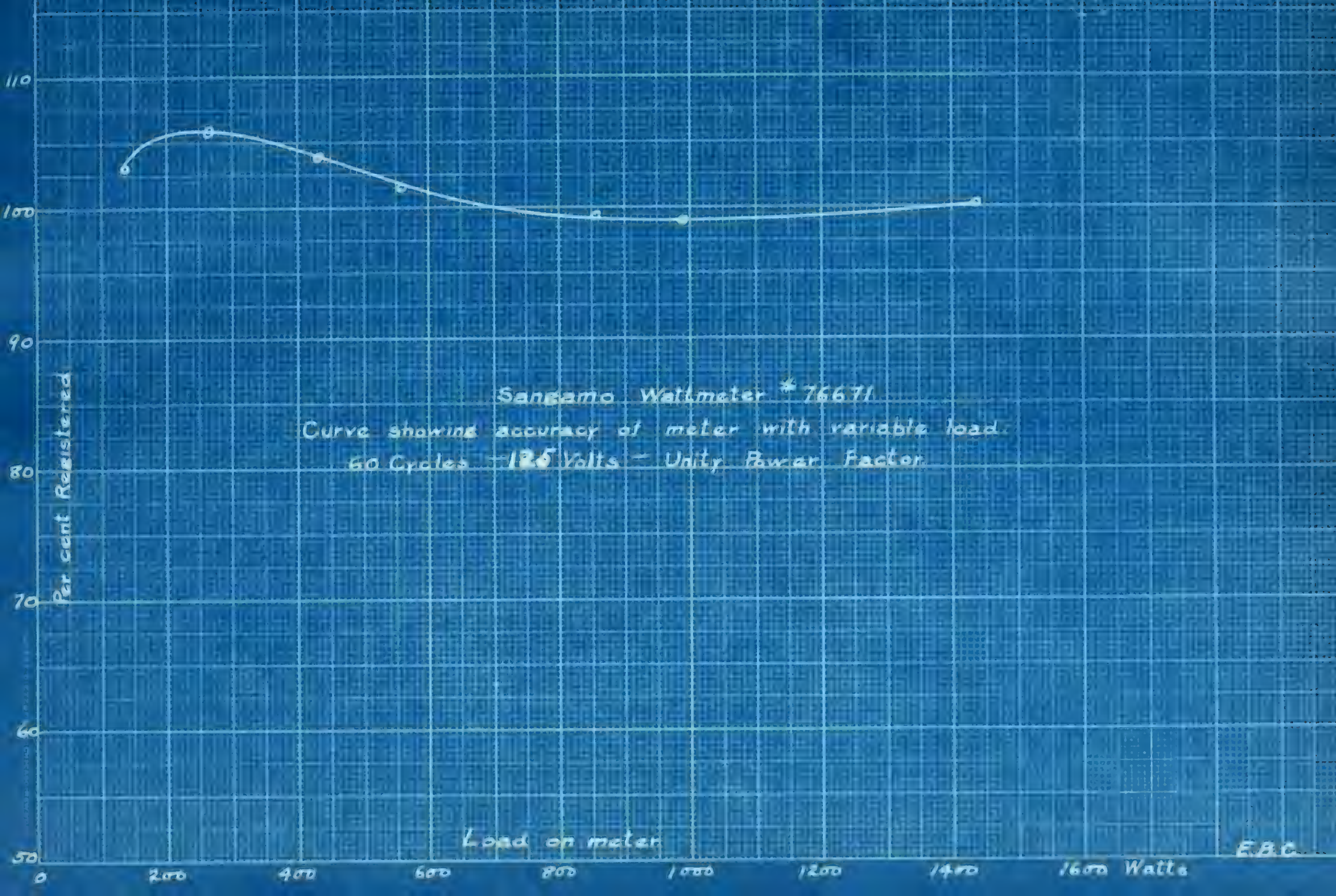
Curve showing accuracy of meter with variable load.

60 Cycles — 100 Volts — Unity Power Factor

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 125 volts, 60 cycles, and unity power factor.

Standard	Meter	R.	T...	%.	E.
1434	1440	20	25	100.3	125
990	979	15	27.6	98.9	125
853	850	15	31.8	99.5	125
558	567	8	25.4	101.5	125
430	447	6	24.2	103.9	125
264	279	4	25.8	105.8	125
138	142	2	25.4	103	125



Sangamo Wattmeter # 76671

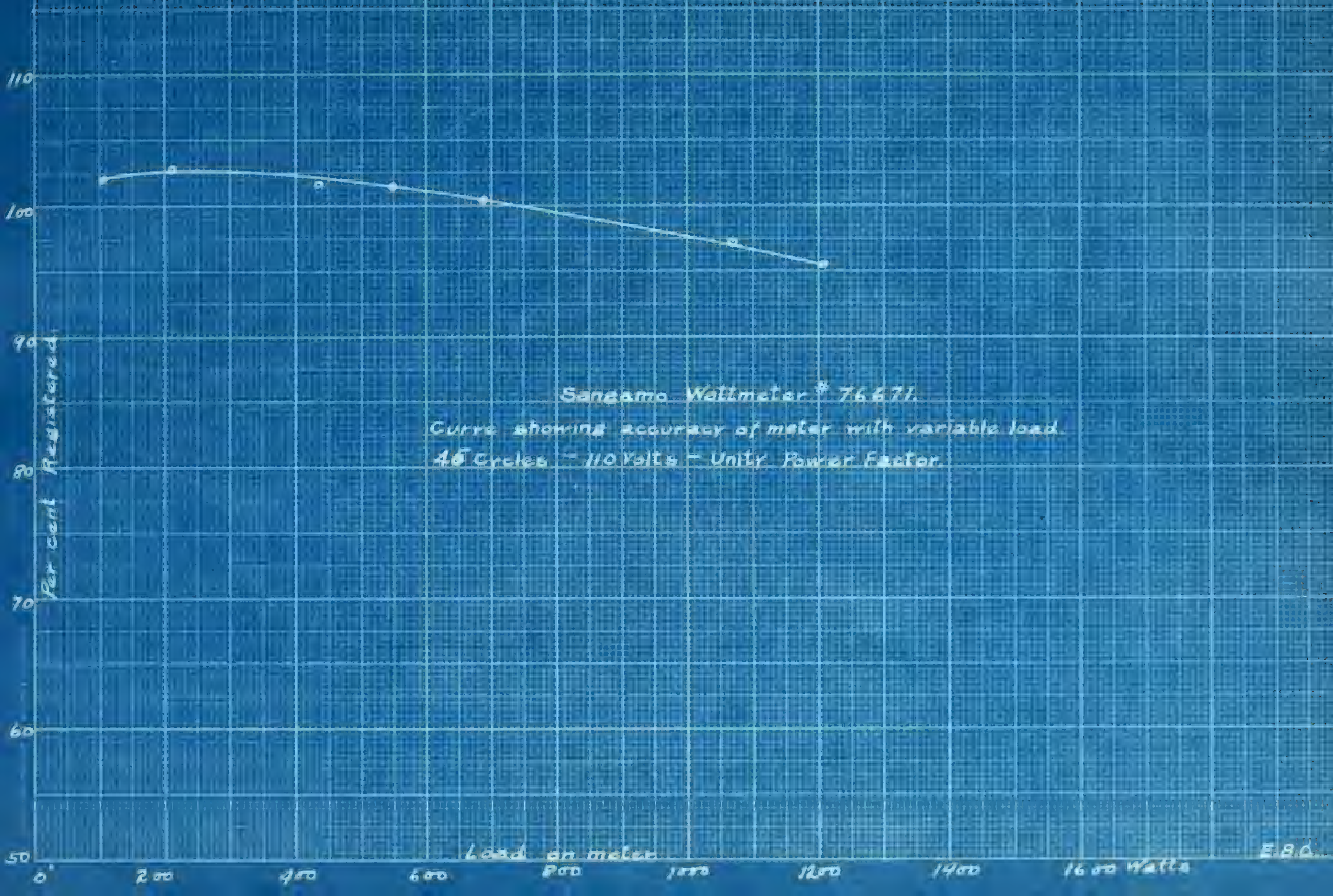
Curve showing accuracy of meter with variable load.

60 Cycles – 125 Volts – Unity Power Factor

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 110 volts, 45 cycles, and unity power factor.

Standard Watts.	Meter Watts.	R.	T.	%.
1210	1153	15	23.4	95.4
1070	1040	15	26	97.3
690	693	10	26	100.4
550	558	8	25.8	101.3
438	445	10	40.4	101.5
210	216	3	25	102.8
107	109	2	33	102



Sangamo Wattmeter # 76471.

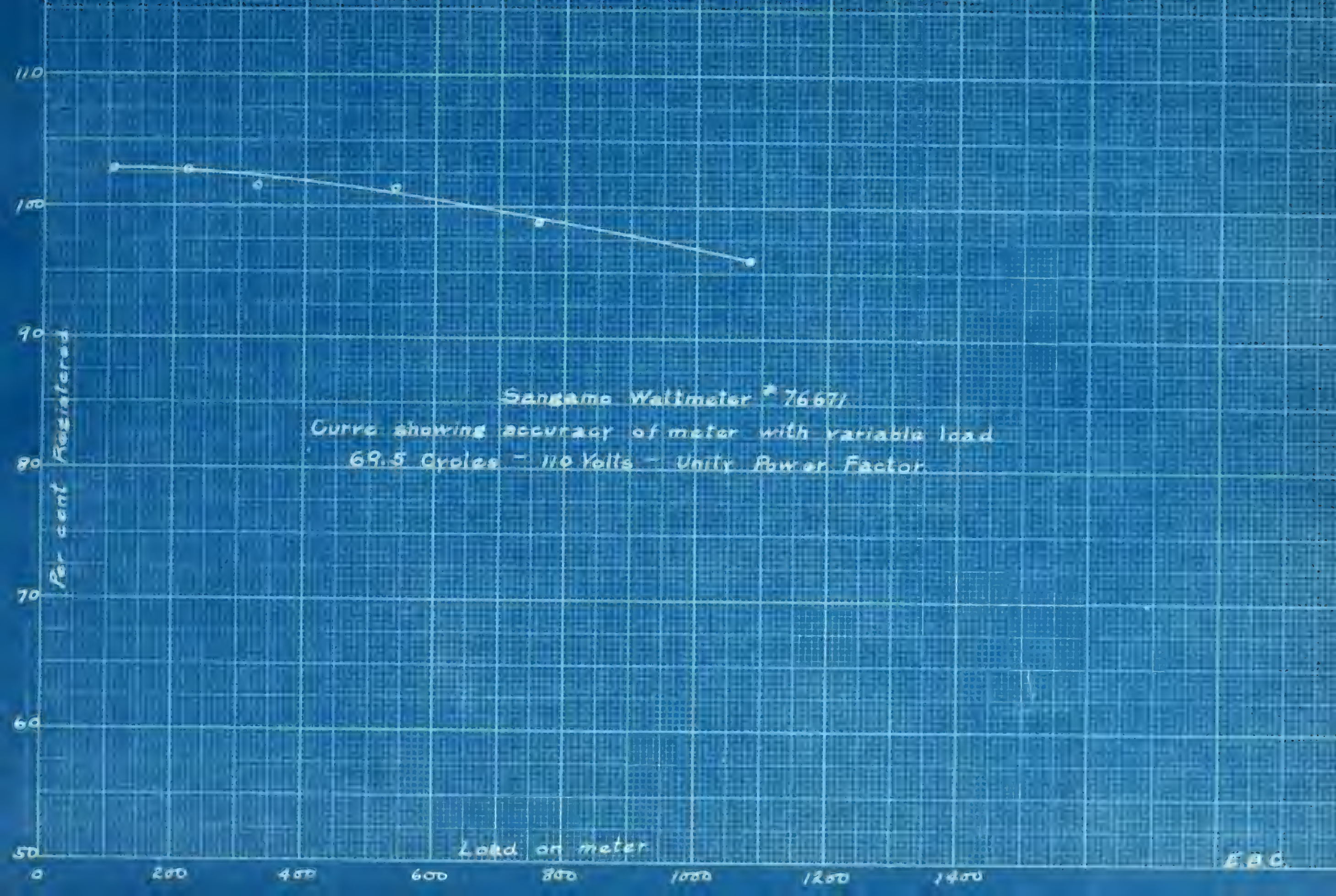
Curve showing accuracy of meter with variable load.

46 Cycles – 110 Volts – Unity Power Factor.

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 110 volts, 69.5 cycles, and unity power factor.

Standard Watts.	Meter Watts.	R.	T.	%.
1080	1040	15	26	96
1410	1405	20	25.6	99.7
760	750	10	24	98.8
540	548	8	26.3	101.5
328	333	5	27	101.5
220	226	4	31.8	102.7
107.5	110.3	2	32.6	102.8



Sangamo Wattmeter # 76671

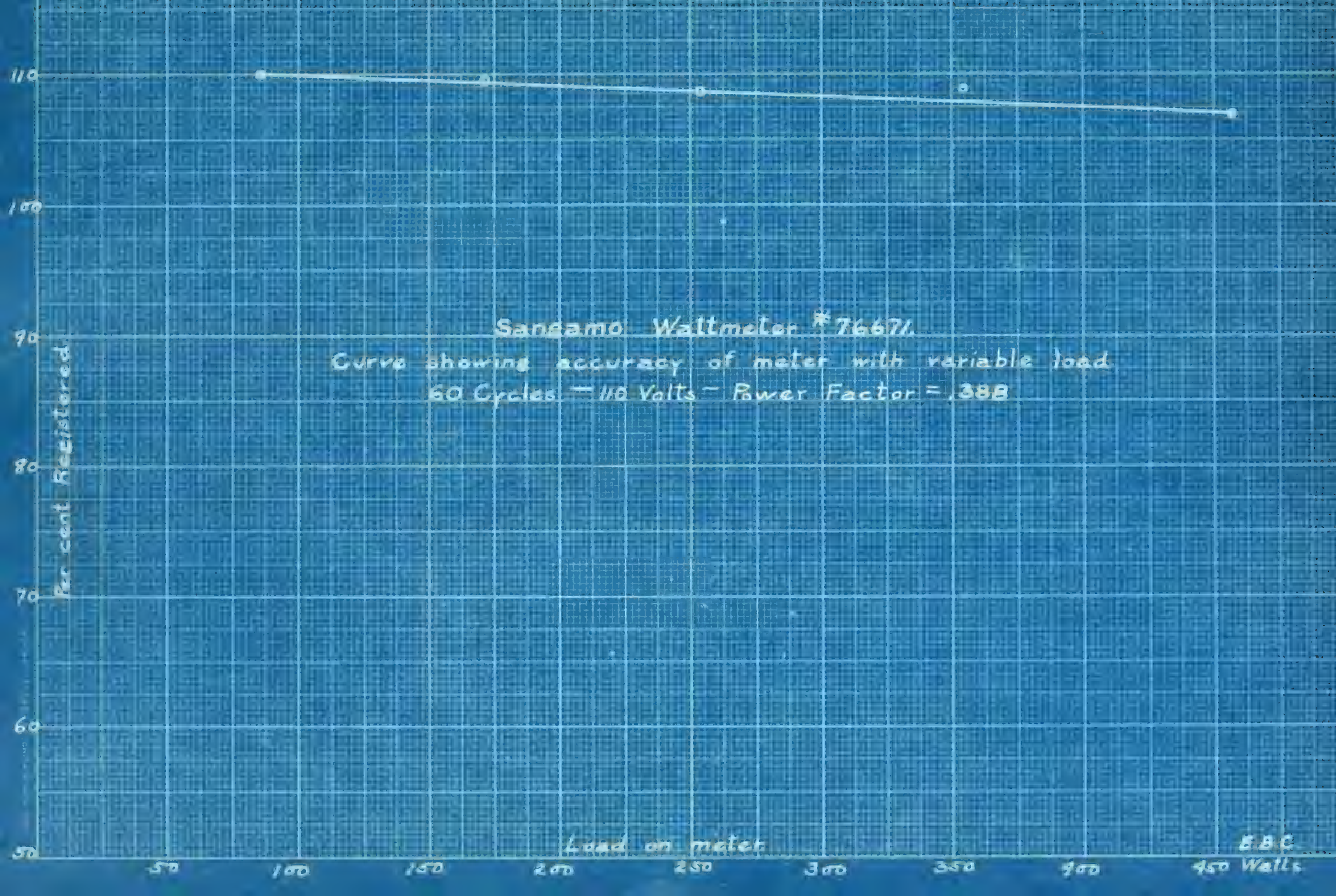
Curve showing accuracy of meter with variable load

69.5 Cycles – 110 Volts – Unity Power Factor

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 110 volts, 60 cycles, and a power factor of .388.

Standard Watts.	Meter Watts.	R.	T.	%.
457	490	8	29.4	107
354	386	6	28	109
253	275	4	26.2	108.7
171	187.5	2	19.2	109.6
85.5	94	2	38.3	110



Sangamo Wattmeter #76671.

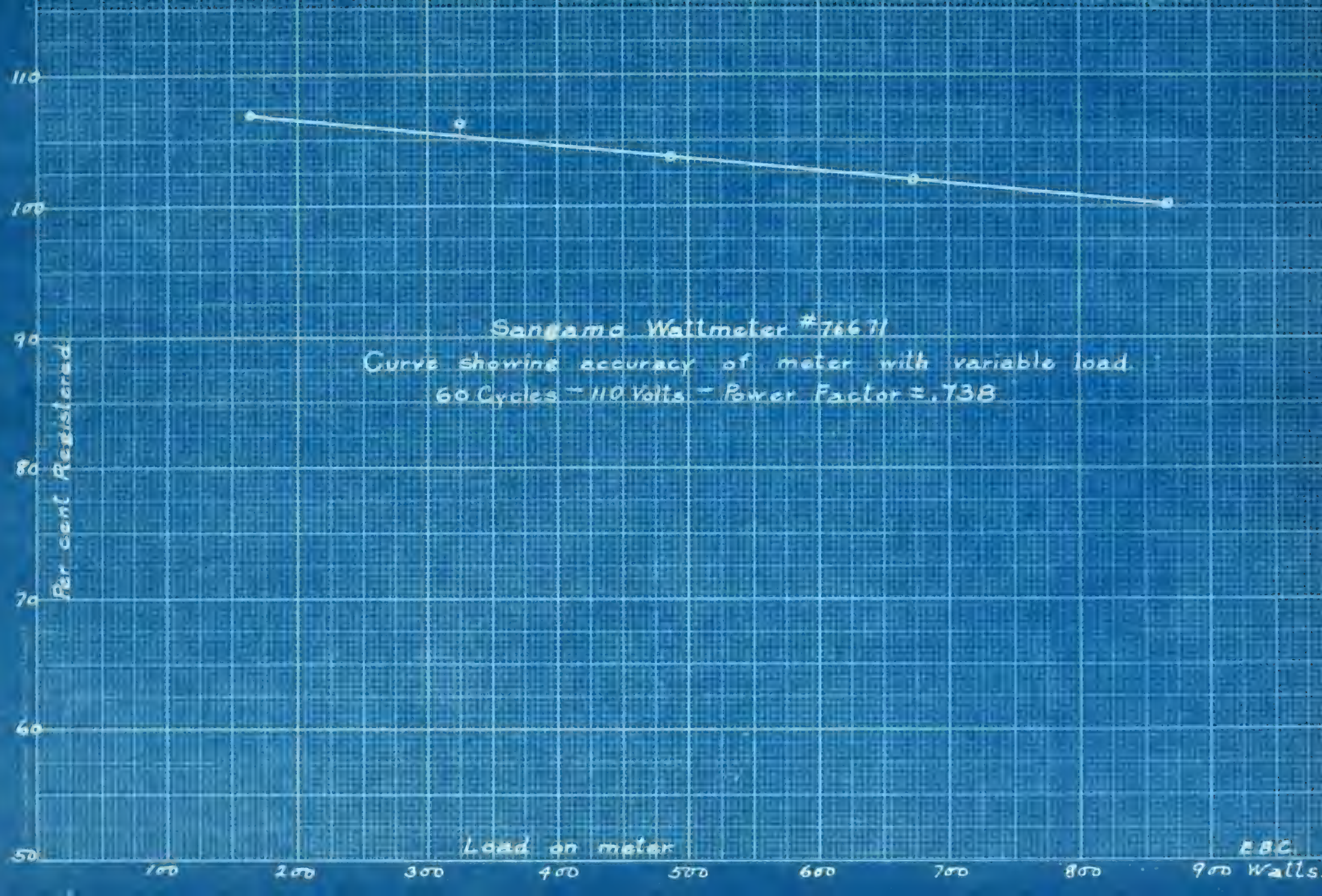
Curve showing accuracy of meter with variable load

60 Cycles — 110 Volts — Power Factor = .388

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 110 volts, 60 cycles, and a power factor of .738.

Standard Watts.	Meter Watts.	R.	T.	%.
867	868	15	31.1	100.1
673	687	10	26.2	102
487	505	8	28.5	103.8
325	346.6	6	31.2	106.5
162.5	174	2	20.7	107



Sangamo Wattmeter #76671

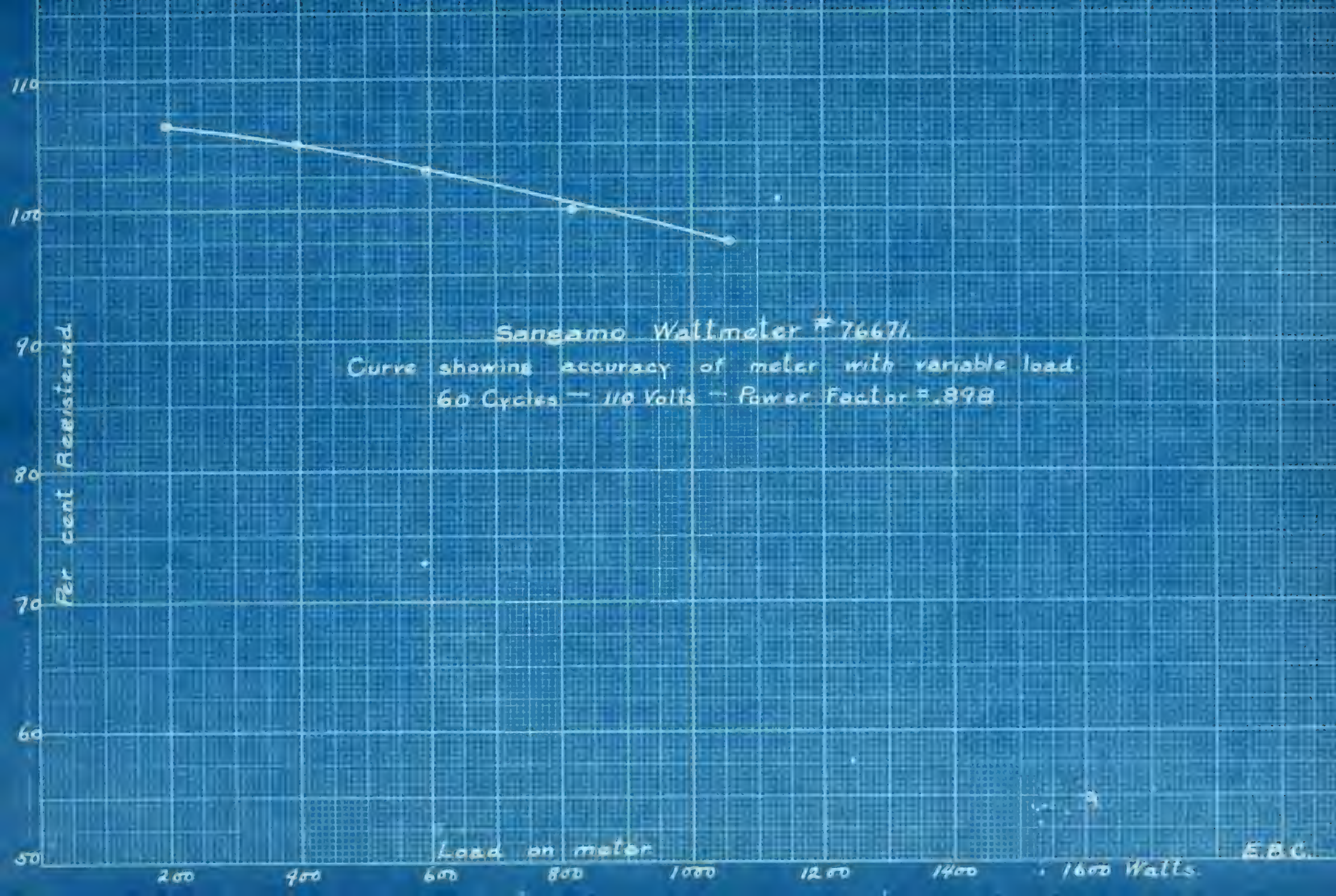
Curve showing accuracy of meter with variable load.

60 Cycles - 110 Volts - Power Factor = .738

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 110 volts, 60 cycles, and a power factor of .898

Standard Watts.	Meter Watts.	R.	T.	%.
1055	1030	15	26.2	97.6
819	819	10	22	100
592	610	8	23.6	103
395	416	8	34.6	105
198	211	4	34.1	106.5



Sangamo Wattmeter # 76671.

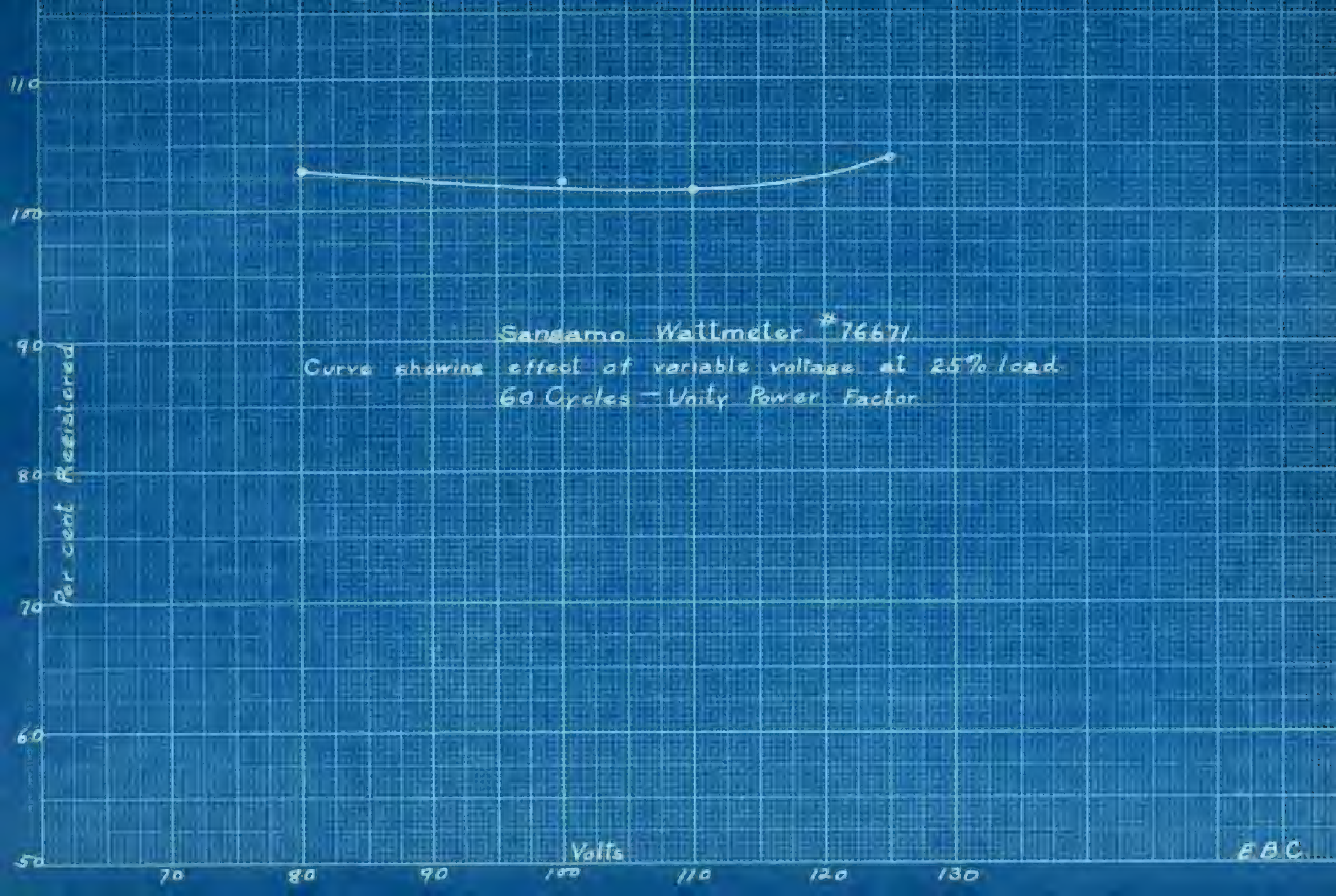
Curve showing accuracy of meter with variable load

60 Cycles — 110 Volts — Power Factor = .898

SANGAMO METER #76671.

Data showing the effect of varying the voltage when the meter is operated at 60 cycles, unity power factor, and 25% load.

Standard Watts.	Meter Watts.	R.	T.	%.	E.
275	283	4	25.4	103	80
275	281	4	25.6	102.2	100
275	279	2	25.8	101.5	110
275	286	4	25.2	104	125



Sangamo Wattmeter #76671.

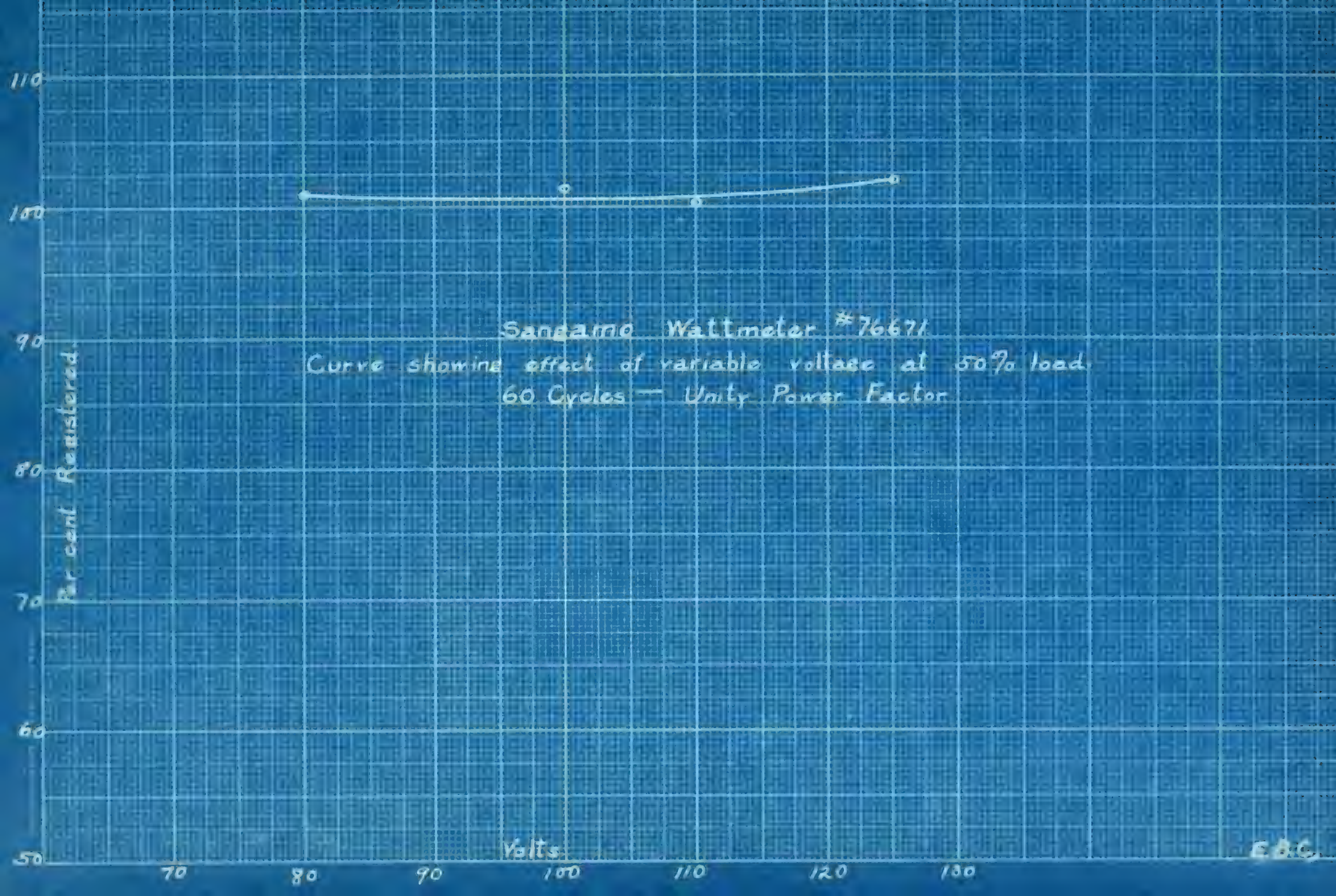
Curve showing effect of variable voltage at 25% load.

60 Cycles – Unity Power Factor.

SANGAMO METER #76671.

Data showing the effect of varying the voltage when the meter is operated at 60 cycles, unity power factor, and 50% load.

Standard Watts.	Meter Watts.	R.	T.	%	E.
550	555	8	26	101	80
550	558	8	25.8	101.5	100
550	552	8	26.1	100.2	110
550	561	8	25.7	102	125



Sangamo Wattmeter #76671

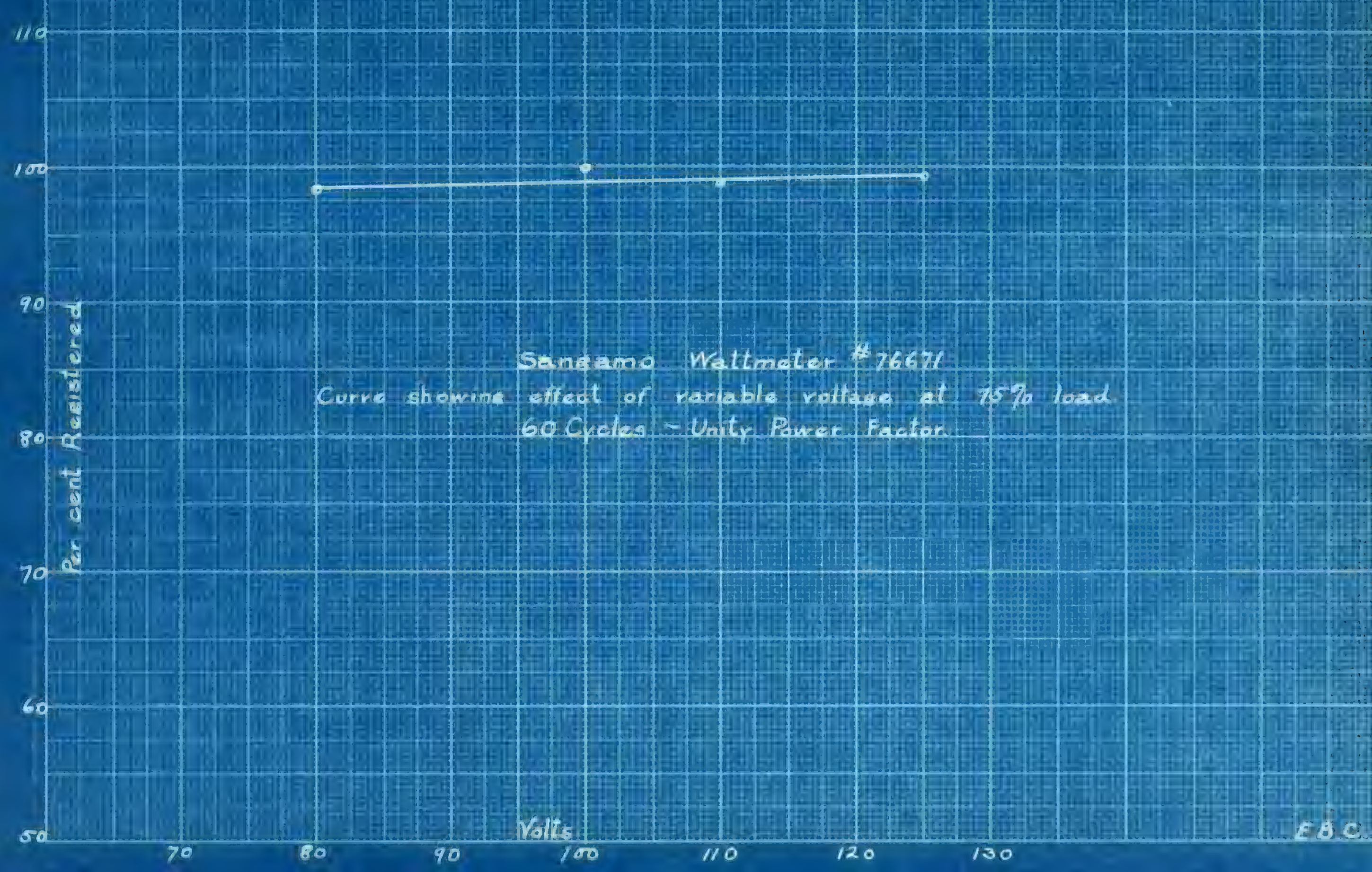
Curve showing effect of variable voltage at 50% load.

60 Cycles — Unity Power Factor

SANGAMO METER #76671.

Data showing the effect of varying the voltage when the meter is operated at 60 cycles, unity power factor, and a load of 75%.

Standard	Meter	R.	T.	%.	E.
825	811	15	33.3	98.3	80
825	825	15	32.7	100	100
825	813	15	33.2	98.7	110
825	818	15	33	99.2	125



Sangamo Wattmeter #76671

Curve showing effect of variable voltage at 75% load

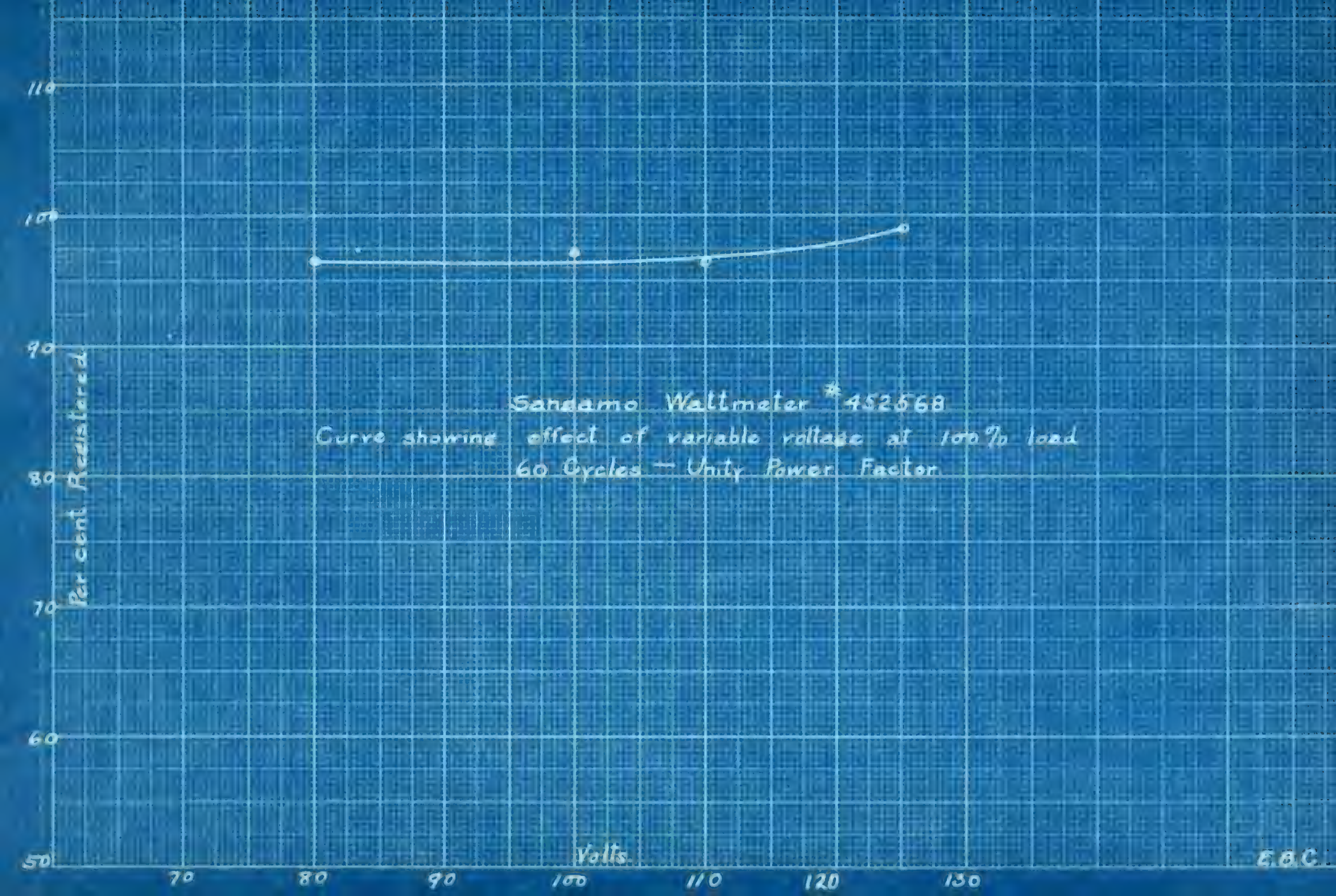
60 Cycles - Unity Power Factor

E.B.C.

SANGAMO METER #76671.

Data showing the effect of varying the voltage when the meter is operated at 60 cycles, unity power factor, and 100% load.

Standard Watts.	Meter Watts.	R.	T.	%.	E.
1100	1060	15	25.5	96.5	80
1100	1071	15	25.2	97.3	100
1100	1060	15	25.5	96.5	110
1100	1089	15	24.8	99	125

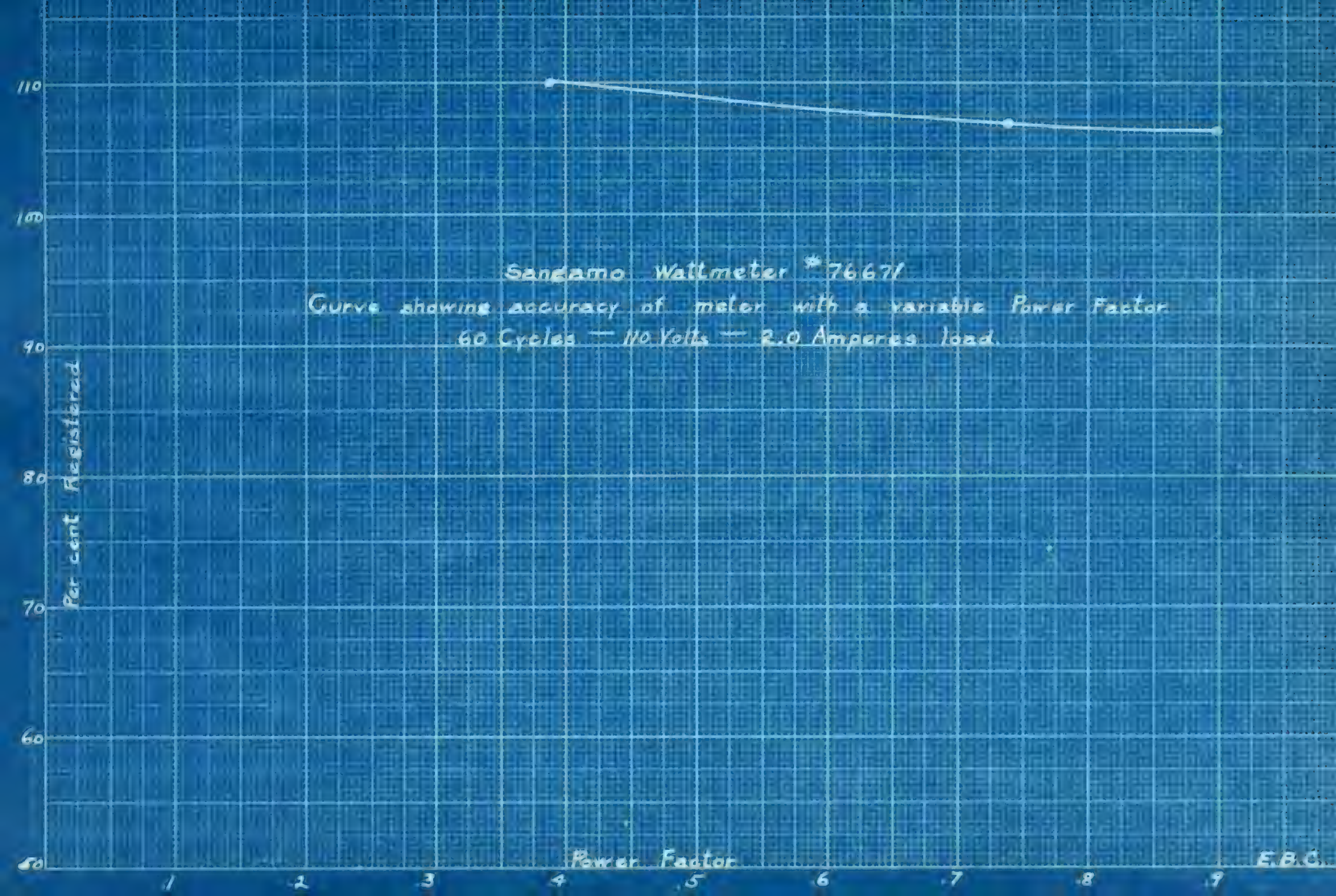


Sangamo Wattmeter # 452568
Curve showing effect of variable voltage at 100% load
60 Cycles – Unity Power Factor

SANGAMO METER #76671.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles, and a load of 2.0 amperes.

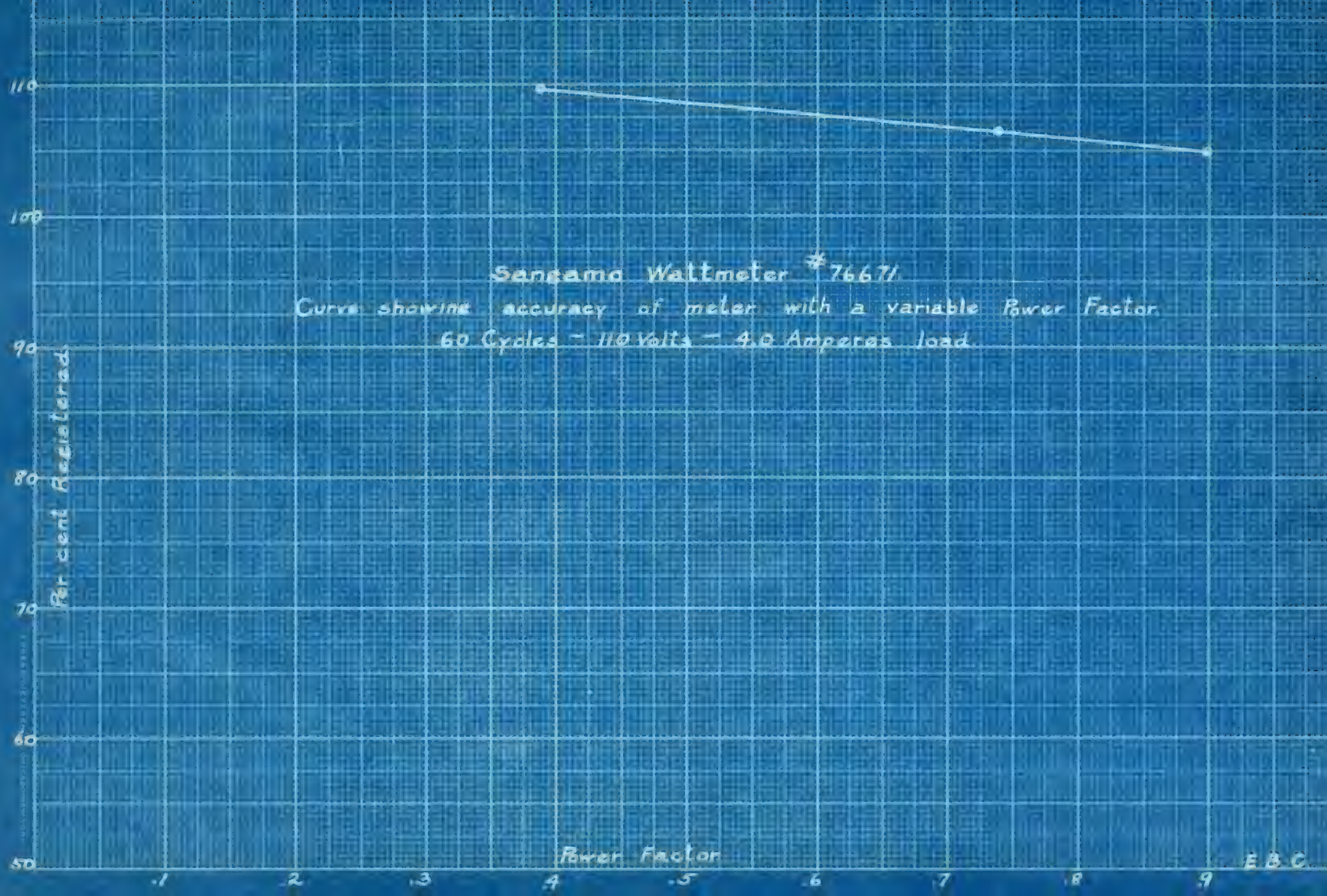
85.5	94	2	38.3	110	.388
162.5	174	2	20.7	107	.738
198	211	4	34.1	106.5	.898


Sangamo Wattmeter #76671
Curve showing accuracy of meter with a variable Power Factor
60 Cycles — 110 Volts — 2.0 Amperes load.

SANGAMO METER #76671.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles, and a load of 4.0 amperes.

Standard Watts.	Meter Watts.	R.	T.	%.	Power Factor.
171	187.5	4	38.4	109.6	.388
325	346	6	31.2	106.5	.738
395	416	8	34.6	105	.898



Sangamo Wattmeter #76671

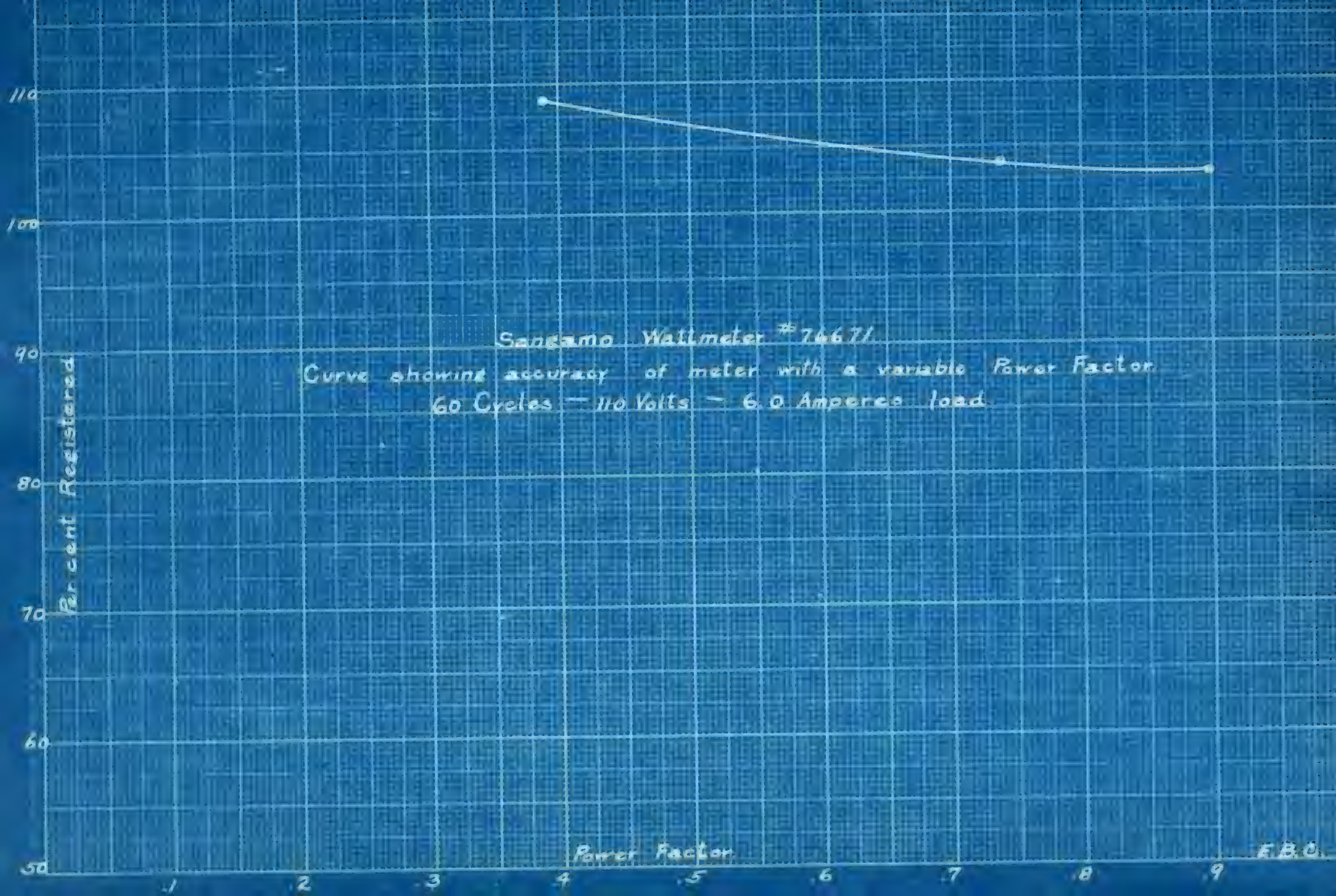
Curve showing accuracy of meter with a variable Power Factor

60 Cycles – 110 Volts – 4.0 Amperes load.

SANGAMO METER #76671.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles, and a load of 6.0 amperes.

Standard Watts.	Meter Watts.	R.	T.	%.	Power Factor.
253	275	4	26.2	108.7	.388
487	505	8	28.5	103.8	.738
592	610	8	23.6	103	.898



Sangamo Wattmeter #74671

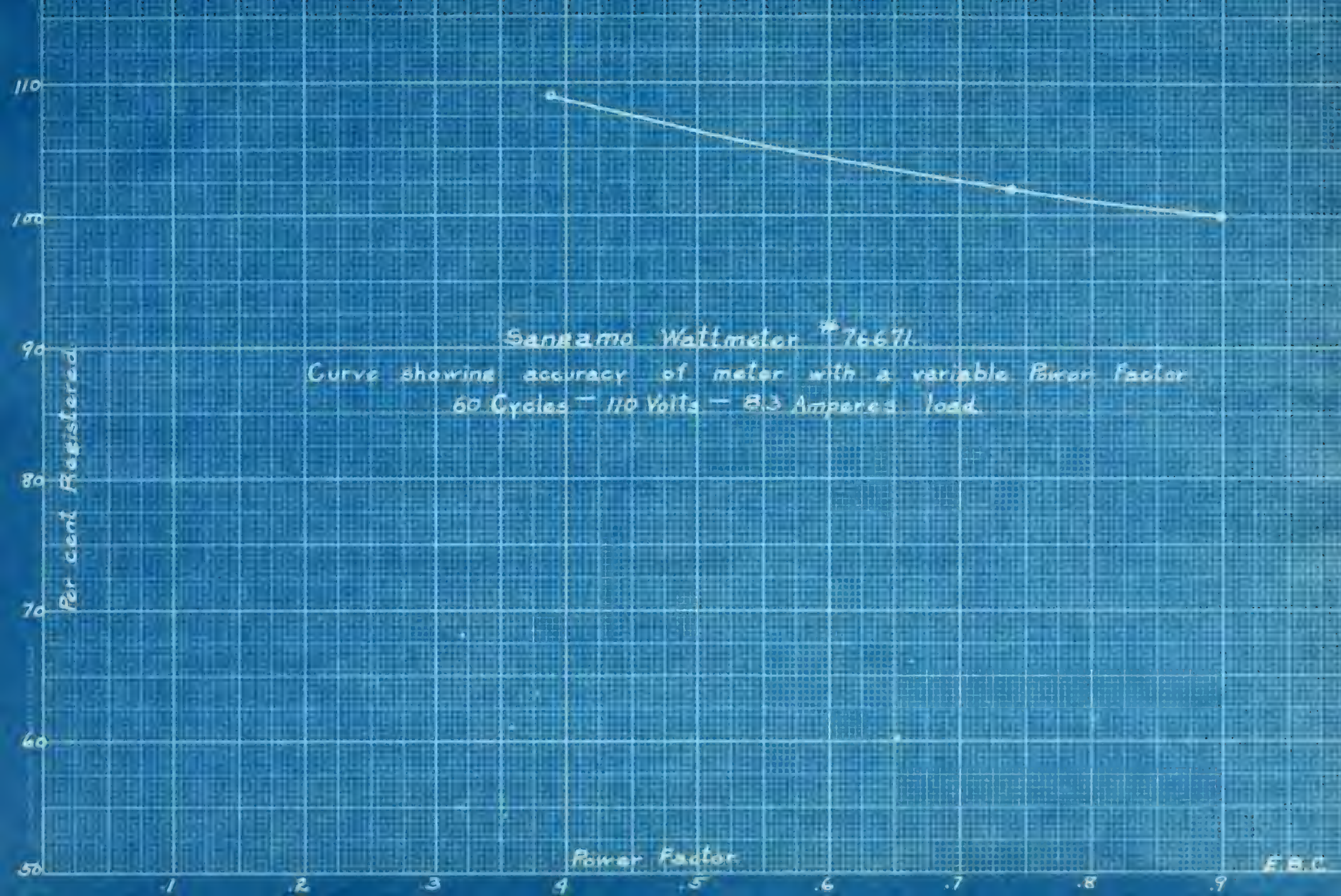
Curve showing accuracy of meter with a variable Power Factor

60 Cycles — 110 Volts — 6.0 Amperes load

SANGAMO METER #76671.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles, and a load of 8.3 amperes.

Standard Watts.	Meter Watts.	R.	T.	%.	Power Factor.
354	386	6	28	109	.388
673	687	10	26.2	102	.738
819	819	10	22	100	.898



Sangamo Wattmeter #76671.

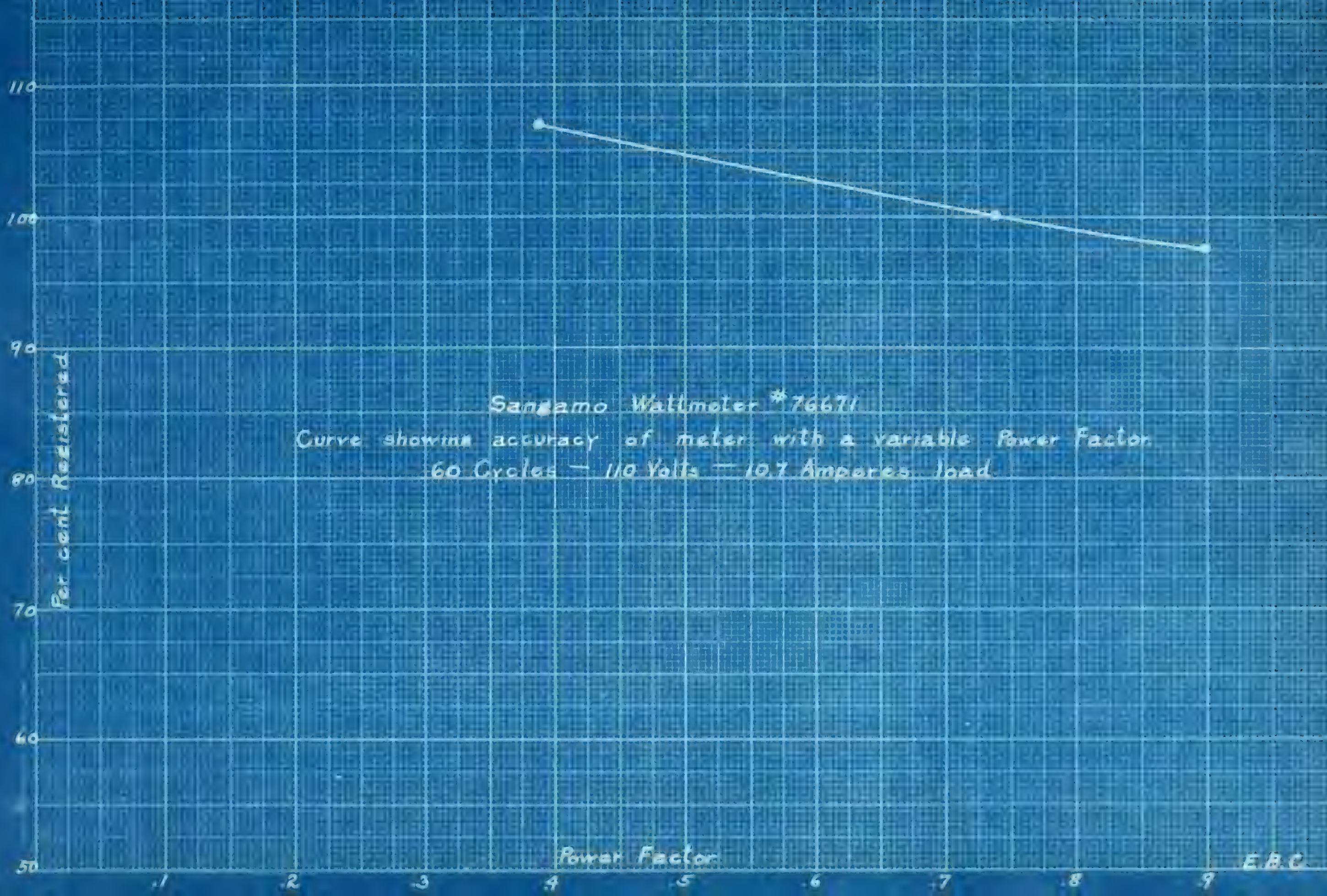
Curve showing accuracy of meter with a variable Power Factor

60 Cycles — 110 Volts — 8.3 Amperes load.

SANGAMO METER #76671.

Data showing the effect of varying the power factor when the meter is operated at 110 volts, 60 cycles, and a load of 10.7 amperes.

Standard Watts.	Meter Watts.	R.	T.	%.	Power Factor.
457	490	8	29.4	107	.388
867	868	15	31.1	100.1	.738
1055	1030	15	26.2	97.6	.898


Sangamo Wattmeter #76671

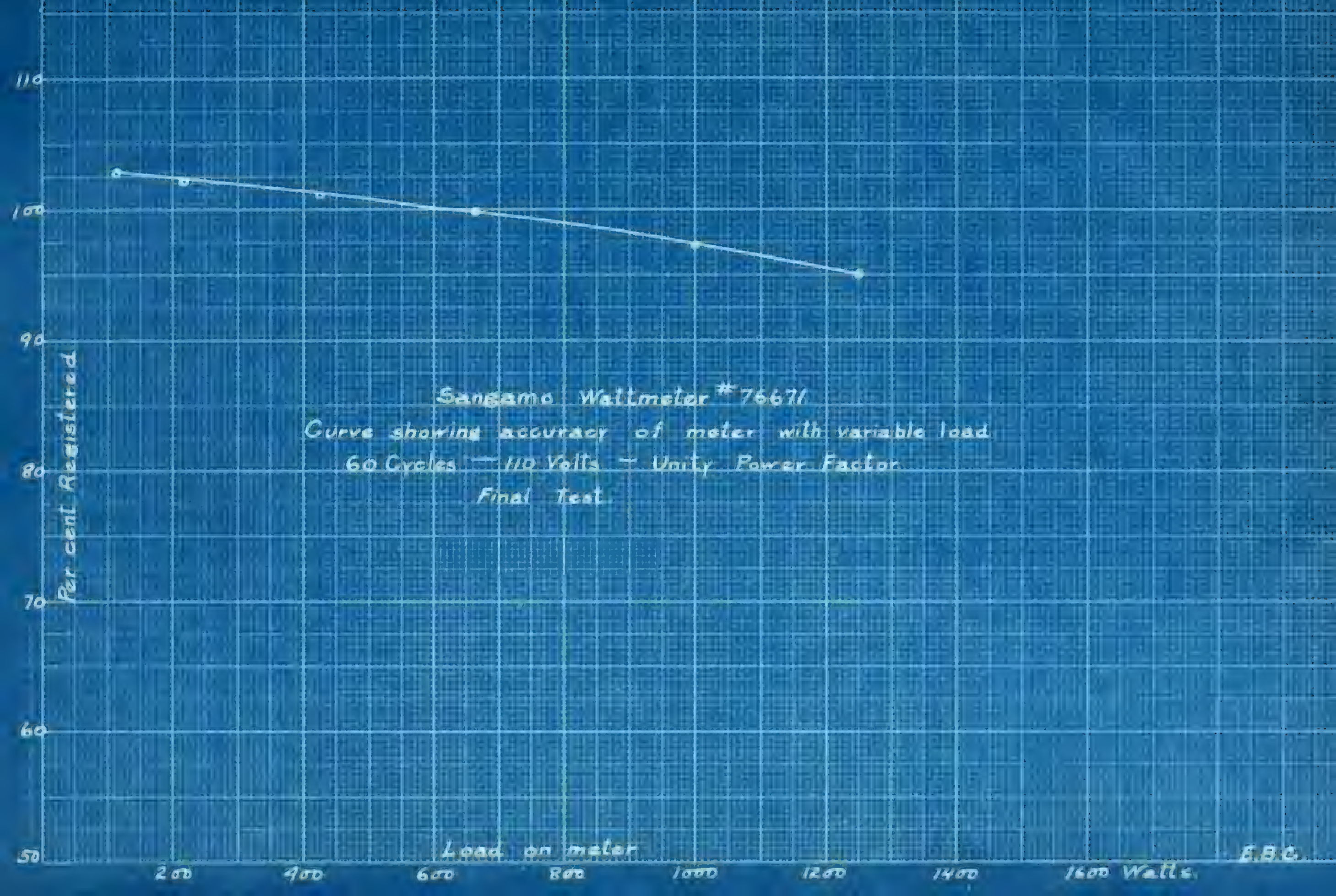
Curve showing accuracy of meter with a variable Power Factor

60 Cycles — 110 Volts — 10.7 Amperes load

SANGAMO METER #76671.

Data showing the effect of varying the load when the meter is operated at 110 volts, 60 cycles, and unity power factor. This is the final test under normal conditions, and was made after the completion of all of the ~~af~~ other tests in order to check up with the initial calibration test.

Standard Watts.	Meter Watts.	R.	T.	%.
1250	1190	15	22.7	95
1000	971	15	27.8	97.1
663	661	8	21.8	99.8
425	429	6	24.6	101
215	219.5	3	24.6	102.1
110	113.1	2	31.8	103



Sangamo Wattmeter #76671

Curve showing accuracy of meter with variable load

60 Cycles — 110 Volts — Unity Power Factor

Final Test

DISCUSSION OF RESULTS.

The curves obtained for the Fort Wayne meter show that the meter holds up very well under all conditions. The initial calibration curve is exceptionally good, the meter registering 100% except on overloads and at 150% overload it is only one per cent slow.

The Sangamo meter does not show up nearly as well as the Fort Wayne meter. I could not obtain a good calibration curve for this meter, for if I adjusted the meter accurately on 100% load, then it would run very fast on light loads. If I adjusted it on light loads then it would run very slow on heavy loads. I compromised by adjusting it on about a 50% load. Then it ran fast on light loads, and slow on heavy loads. The Fort Wayne meter had a tendency to run slightly fast on very light loads, but this was not nearly as pronounced as in the Sangamo meter.

On low voltages the Fort Wayne meter had a tendency to run slightly fast, and on high voltages it ran slow, but at all times it came within 2%.

Varying the frequency from 45 to 63.5 cycles seemed to have little effect on the accuracy of the meter.

On low power factors the Fort Wayne meter has a tendency to run a trifle fast.

At low voltages the Sangamo meter runs faster than under normal conditions, and at high voltages it more nearly accurate.

Varying the frequency seemed to have little effect on the accuracy of the Sangamo meter, and in this respect it is as good as the Fort Wayne meter.

On low power factors the Sangamo meter runs very much faster than when operated under normal conditions.

In conclusion I would say that the Fort Wayne meter is much better than the Sangamo meter for circuits where the voltage, power factor, or load is going to vary.